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THREAD GRINDING
AND MEASUREMENT

THREAD GRINDING AND MEASUREMENT

BY

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PREFACE

THREAD GRINDING is no longer an operation associated exclusively with gauge production and other work on which extreme accuracy is the principal objective, but is now a regular manufacturing operation finding a wide application as a normal production process. Present-day machines and abrasive wheels are developed to such a pitch that thread grinding on screws, nuts, worms, hobs, etc., can be undertaken without considerable experience, as was demonstrated in the war of 1939–45, during which much of this grinding was done by trainee and female labour. On production thread grinding high output rates can be maintained to fine limits, the unit cost per component being relatively low.

In the preparation of this book we have aimed at providing a series of interesting chapters, sequentially arranged, as far as possible, to serve as a useful reference to beginners as well as more experienced personnel on both the production and inspection sides of thread-ground work. So far as we are aware, there is at present no other book devoted entirely to thread grinding and thread measurement, although of course aspects of the subject have been dealt with from time to time in separate articles which have appeared in various engineering journals and official publications. References to some of these will be found in the text.

We gratefully acknowledge a considerable amount of co-operation from firms specializing in the manufacture of thread-grinding machines and abrasive wheels, e.g. the grinding-wheel recommendations set out in various chapters have been approved by leading manufacturers. In regard to thread measurement, a fairly considerable amount of space is devoted to the wire methods. This, we feel sure, will be appreciated by many practical men. Thread terms and definitions have been classified and explained in detail, the same applying to limit systems in general and their special applications to screw threads, worms, and hobs. Lastly, we trust it is not a vain hope that the considerable range of useful tables, mainly grouped at the end of the book for ready reference, all having direct relevance to precision screw-thread production and measurement, will combine with the other illustrated notes and descriptions to make this a useful reference book to all engaged in precision thread grinding and inspection.

Thanks are tendered to the following firms for ready and courteous co-operation: Adam Machine Tool Co., Ltd.; Messrs. Alfred Herbert, Ltd.; Coventry Gauge and Tool Co., Ltd.; Messrs. Charles Churchill & Co., Ltd.; The Carborundum Co., Ltd.; Messrs. David Brown & Sons (Huddersfield), Ltd.; The Ex-Cell-O Corporation; Messrs. Thomas Firth and John Brown, Ltd.; Hamber Engineering Co., Ltd.; Messrs. A. A. Jones & Shipman, Ltd.; Messrs. E. H. Jones (Machine Tools), Ltd.; Jones & Lamson Machine Co.; Landis Tool Co.; Messrs. W. H. Marley

& Co., Ltd.; Newall Engineering Co., Ltd.; Norton Grinding Wheel Co., Ltd.; Optical Measuring Tools, Ltd.; Pitter Gauge and Precision Tool Co., Ltd.; Technical Diamonds, Ltd.; and Vickers, Ltd.

Grateful acknowledgment is also made to the British Standards Institution, 28 Victoria Street, London, S.W.1, for permission to reprint various definitions, recommendations, and tables from Standards associated with screw threads, worms, limit systems, etc. A list of British Standards applicable to mechanical engineering is obtainable gratis from the Institution.

A. C. P.
W. H. D.

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CHAPTER I

INTRODUCTION

THREAD grinding is one of the newer developments of the grinding process which, like various other more recently developed machining processes, made considerable headway under the impetus of war-time requirements. It is now one of the regular manufacturing operations, its numerous advantages having become so widely recognized that it is accepted as being just as essential to resort to thread grinding to produce precision threads as it is to employ grinding and similar methods to produce accurate cylindrical or flat surfaces. Apart from the small-scale production of ground-thread taps by a few firms on a commercial basis, until a few years ago the only thread grinding done in British or American practice was almost confined to special jobs calling for extreme accuracy. Nowadays, however, a number of firms produce commercial machines for high production precision thread grinding. The development of this class of grinding machine would not have been possible, of course, had not the wheel makers been able to produce abrasive wheels capable of standing up to high-speed duty. Some justification can be made out for the view that the wheel controlled the progress of machine design. Silicon carbide (referred to on page 47) was discovered by Dr. E. Acheson in the early 'nineties. All modern grinding processes owe much to the research and perseverance that culminated in the production of the first commercially useful vitrified wheels. The Norton Grinding Wheel Co. and the Carborundum Co. are two of several well-known firms whose research and enterprise in the field of grinding wheel manufacture have contributed largely to this end. Both these firms have co-operated with the authors in providing up-to-date technical information.

The technique of wheel dressing has been developed through many phases during the past twenty years and is still being improved upon. Dressing devices have been designed in a great variety of forms, some accurate as well as ingenious when applied to thread sections having controlled radii. In this connexion it can confidently be stated that British designs of dressing apparatus are second to none.

COMPARISON WITH OTHER METHODS. The first object of thread grinding is to produce accurate threads—single or multi-start in a wide range of pitches, commonly from 2 t.p.i. to 60 t.p.i.—in hardened or unhardened steel at a fraction of the time taken to produce them by means of point-tool methods, followed by such operations as chasing and lapping. Threaded parts, such as hobs, taps, and a whole range of thread-producing tools laboriously finished to size by older methods, e.g. chasing and milling, are invariably distorted to some extent during subsequent heat-treatment processes. On a thread-grinding machine it is possible to grind the threads from the solid in hardened material, so that "plain diameters" and "thread

diameters" are perfectly concentric about a common axis in the finished product, and distortion errors of pitch, form, drunkenness, or straightness do not arise. Another point in its favour is that thread grinding overcomes the ill-effects of over- or de-carburization of the surfaces of the blanks.

Pre-cut threads which have been cut by a tooling method, or by milling, and have subsequently been heat-treated, can be finished by the thread-grinding process, during which any errors of distortion are removed. It must be emphasized, however, that whilst thread grinding can advantageously be employed for this finishing process it is not confined to such an operation—in fact at the present time it is used far more widely in producing threads "from the solid," although very coarse threads are usually "roughed out" or "pre-cut" in a preliminary operation before being ground. A particularly important application of thread grinding is in the production of ground-thread taps, hobs for thread milling, etc. It must not be assumed that thread-grinding machines are suitable only for tool-room purposes. On the contrary, they have now become recognized as of great practical use on a wide range of repetition work where fine limits are required at low cost per work piece. In gauge production, of course, the main emphasis is placed on dimensional accuracy.

FIG. 1. GROUND-THREAD TAPS
As indicated by the marking, these are carbon steel taps.
Reproduced by courtesy of Messrs. Thos. Firth & John Brown, Ltd., who also supply high-speed steel ground thread taps.

FACTORS UPON WHICH SUCCESSFUL RESULTS DEPEND.

Good thread-grinding results depend upon many factors discussed in detail in succeeding chapters. Among these factors are—

(1) The use of a grinding wheel suitable for the job in hand.

(2) The use of a correct wheel-work speed ratio.

(3) The use of a suitable cutting fluid or coolant during both the grinding and dressing operations.

(4) The use of suitable diamonds and the adoption of correct wheel-dressing procedure (whether the wheel be diamond-dressed or crushed).

(5) The choice of correct depth for grinding cuts.

(6) The use of a steady rest so designed and used as to prevent deflection of the relatively longer workpieces due to the action of the abrasive wheel or to their own weight.

CHAPTER II

TYPICAL MODERN THREAD-GRINDING MACHINES

At this early stage in our treatment of thread grinding, we give our readers descriptions of some modern thread-grinding machines.

THE NEWALL THREAD-GRINDING MACHINES. The Newall Model 836 Thread-grinding Machine has a pleasing appearance, all motors being mounted in the machine interior and isolated from the bed so that this usual source of vibration is eliminated. See Figs. 2 and 3.

The design of this machine allows a conveniently grouped and positioned means of control in operation, with push-button electrically-operated motors and a clearly graduated fine-feed control wheel with positive increments of 0·0002 in. on the diameter of the work.

The wheel spindle has a variable speed range up to 5000 s.f.p.m. with a wheel size of 16 in. diameter, and a face width of wheel up to $1\frac{3}{4}$ in. The method of wheel dressing is by a diamond-dresser unit mounted above the abrasive wheel so that the wheel may be formed and re-trued when required without altering the position of the head-stock or tailstock. The drive for the diamond-dressing mechanism is by means of a flexible drive from a $\frac{1}{8}$ h.p. motor.

Provision is also made for wheel dressing with crusher rollers which can be changed over from the diamond dresser in a few minutes.

Much attention has been paid in design to ensure that the machine will maintain a high output of internal and external ground threads with a high order of accuracy, yet the operational and work-setting controls do not require a high degree of skill on the part of the operator.

The machine is equally suitable for gauge work as it is for mass-production grinding, the capacity of the machine being one of its outstanding features, as will be appreciated from the following—

Max. grinding diameter with new wheel, 8 in.
Max. grinding length, 20 in.
Max. length between centres, 36 in.
Max. length ground internally, 3 in.
Max. internal diameter, 7 in.
Min. internal diameter, $\frac{3}{4}$ in.
Work-speed range, $\frac{1}{2}$ to 20 r.p.m.
Range of threads, $2\frac{1}{2}$ to 48 t.p.i.
Floor space required, 8 ft $\times$ 5 ft.

The feed for plunge-cut grinding is infinitely variable.

The machine is manufactured by The Newall Engineering Co., Ltd., Peterborough, England, the Sole Agents for Great Britain being Messrs. E. H. Jones (Machine Tools), Ltd., The Hyde, London, N.W.9. By the courtesy of the latter, the Newall Thread Grinder, Model 836, is illustrated in Fig. 2.

Another model in the range of Newall thread-grinding machines is

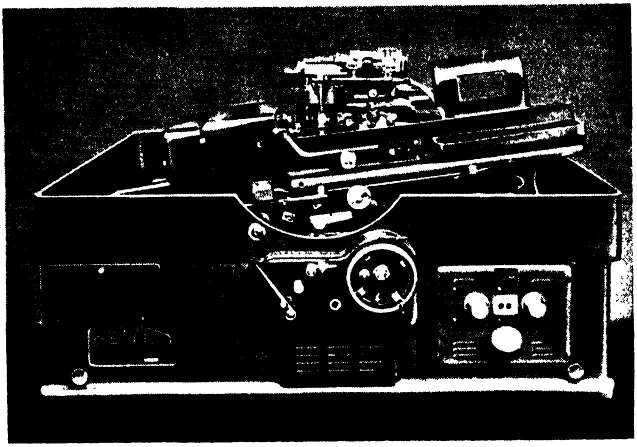


FIG. 2. THE NEWALL MODEL 836 THREAD-GRINDING MACHINE

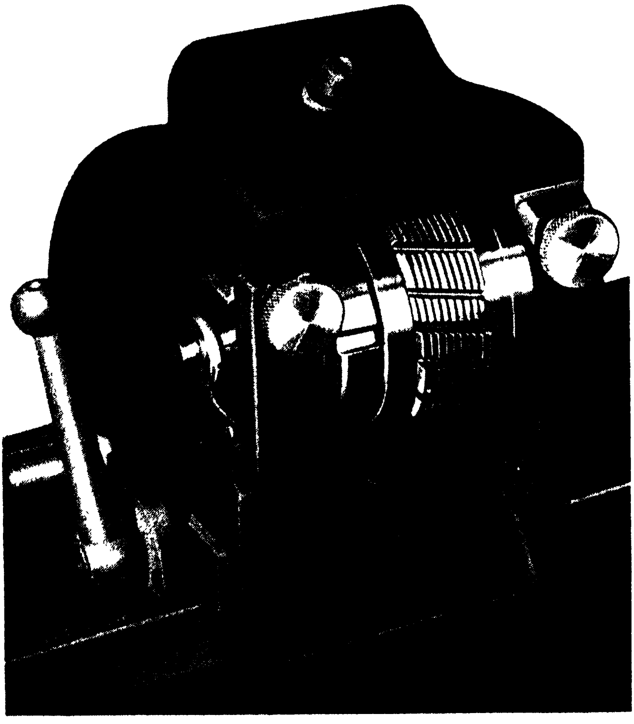


FIG. 3. WHEEL-CRUSHING ATTACHMENT FOR NEWALL MACHINE

the Model 420 which allows a work length of 20 in. between centres and a centre height of $2\frac{1}{4}$ in.

In Fig. 3 is shown the wheel-crushing attachment which is supplied, if desired, with the Newall Model 420. In this illustration the design of the crushing roller (with its spiral, and annular groves) is apparent. This attachment works from the table of the machine and will crush wheels up to 1 in. wide. It is interchangeable with the diamond dresser.

On both models provision is made for single-rib traverse grinding, multi-rib traverse, and multi-rib plunge-cut grinding.

MATRIX PATENT THREAD-GRINDING MACHINES. These are manufactured by the Coventry Gauge and Tool Co., Ltd., Coventry, England, a firm with considerable pioneer experience in this work, to whom a great deal of credit is due for the high standard of present-day thread grinding generally. We give a brief description of the Matrix Model No. 16G Thread-grinding Machine, illustrated in Fig. 4, the photograph having been supplied by the makers, who have, in addition, placed other useful technical data at the disposal of the authors.

The Matrix Model No. 16G, whilst being ideally suitable for the production of screw-thread gauges, also incorporates many features of design which make it equally suitable for use in quantity production to a very high standard of accuracy both as regards the finest limits and dimensions and the quality of surface finish in the thread-ground workpieces.

From Fig. 4, which shows a general view of the machine, it will be seen that the thread-grinding machine and the control cabinet are separate units. The latter incorporates a tool drawer and the unit serves as a useful workstand. The functions of the various controls on this unit are tabulated in Fig. 4.

The wheel-dressing equipment consists of (1) the Matrix patent multi-ribbed wheel dresser; (2) the Matrix multi-ribbed wheel crushing device; and (3) the Matrix (Newman's patent) single-rib wheel dresser.

With equipment supplied as standard this machine can produce ground threads as follows: (1) English pitches 8 to 60 t.p.i.; (2) 0·5 to 3 mm pitch Metric, etc.; (3) No. 0 to No. 8 B.A. Of course this range can readily be extended to include other pitches and forms of thread of standard or non-standard proportions. All four methods of grinding described in Chapter III can be used, i.e. the operator can employ (1) single-rib traverse grinding, (2) dual-rib traverse grinding, (3) multi-rib traverse grinding, and (4) multi-rib plunge-cut grinding.

The electrical equipment consists of a dual Ward-Leonard system, driven by a main motor, and includes a 1·2 kilowatt generator for the wheelhead motor and a 0·6 kilowatt generator for the workhead motor. Lubrication of the wheel spindle bearings and the various slides is provided by a mechanical unit. A hand-operated system is used where a mechanical unit cannot conveniently be adopted.

The lead screw has a pitch of 0·1 in. and various pitches are obtained

by the usual arrangement of change-wheels. A pitch-correcting device is built into the machine and provides a most useful means of correcting slight errors in pitch.

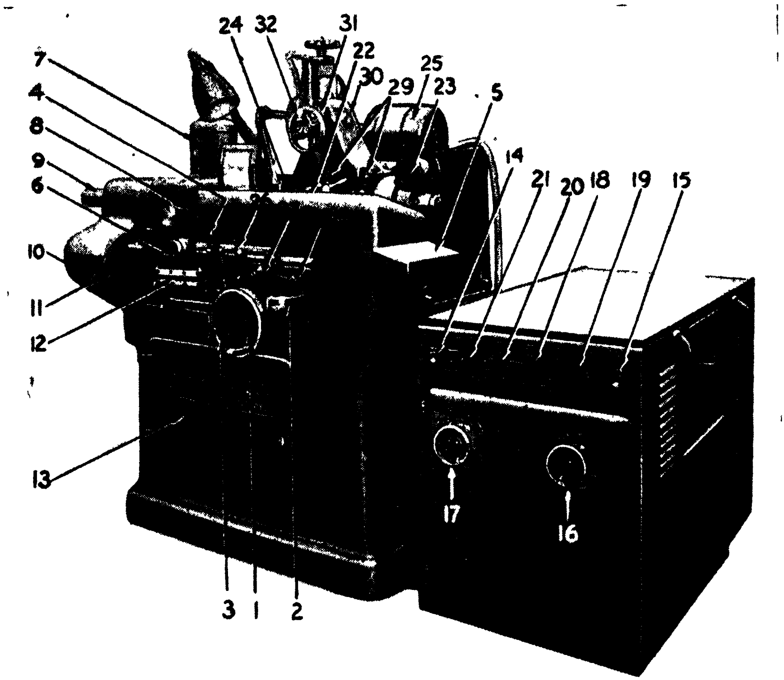


FIG. 4. MATRIX MODEL NO. 16G, THREAD-GRINDING MACHINE

1. In-feed hand wheel.
2. In-feed clock indicator.
3. In-feed vernier locking nuts
4. Hand-control lever for table (forward and reverse).
5. Table slide.
6. Table longitudinal adjustment (side cut).
7. Workhead motor.
8. Oil level indicator for workhead.
9. Spline shaft cover
10. Change-gear cover.
11. Change-gear box.
12. Pitch corrector.
13. Tool cupboard.
14. Main motor start push button.
15. Main motor stop push button.
16. Wheelhead speed-control wheel.
17. Workhead speed-control wheel.
18. Wheelhead control switch.
19. Workhead control switch.
20. Coolant pump control.
21. Right- and left-hand thread control switch.
22. Tailstock.
23. Wheelhead speed indicator.
24. Grinding wheel.
25. Wheelhead motor.
26. Table control dogs.
27. Automatic wheel-trip control lever (quick release).
28. Automatic wheel-control lever bolt (trip lever).
29. Oil-sight feeds for wheelhead.
30. Wheel-crushing device.
31. Wheel-crushing device locking lever.
32. Wheel-crushing device operating hand wheel.

Small amounts of taper may be obtained by moving the tailstock and this is readily brought about by operating a micrometer hand-wheel. The same mechanism may, of course, be employed to correct errors in parallelism which may be present in the workpart.

THE D.B.S. No. 10 WORM-GRINDING MACHINE. Fig. 5 shows the No. 10 worm-grinding machine made by Messrs. David Brown &

Sons (Huddersfield), Ltd., whilst Fig. 6 gives a clear close-up view of a worm in the process of grinding.

This machine embodies many exclusive features as a result of many

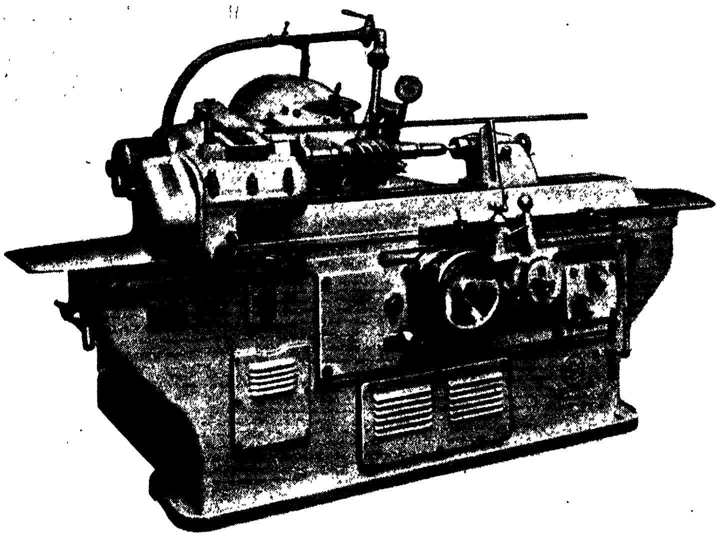


FIG. 5. THE NO. 10 WORM-GRINDING MACHINE
Made by Messrs. David Brown & Sons (Huddersfield), Ltd.

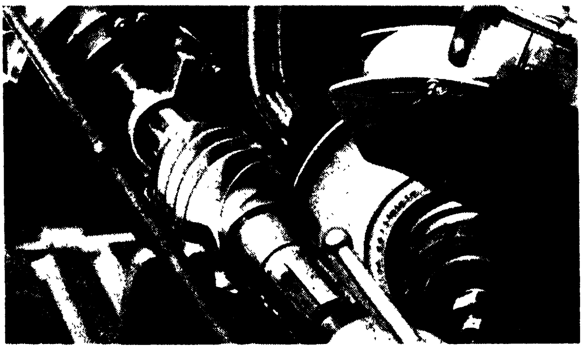


FIG. 6. CLOSE-UP VIEW OF WORM-GRINDING IN THE D.B.S. WORKS

years' experience of grinding worm threads to a particularly high standard of accuracy, and is equally suitable for grinding involute and "David Brown" patent form of worm thread which, like the B.S. worm thread, is an "involute helicoid."

The machine is entirely automatic in operation, the abrasive wheel

being withdrawn from the work at the end of the grinding stroke, whilst indexing is effected during the quick-return stroke.

An independent motor attached to the wheelhead drives the abrasive wheel, and adjustment is provided whereby the latter can be set according to the lead angle of the worm to be ground.

The driving motors are push-button operated and all controls are within easy reach of the operator.

The wheel spindle is mounted on ball bearings of ample proportions, the axial thrust due to the abrasive wheel being taken by ball thrust bearings. The wheel spindle can be adjusted axially to compensate for wear of the abrasive wheel.

Six changes of speed are provided by the work-table gear box which has sliding gears. The quick return stroke is made at constant speed and is not affected by the lead of the worm or the speed of the cutting stroke.

The work headstock contains the gearing for both the rotation and indexing of the worm, and is designed with a live spindle running in adjustable bronze bearings. Special consideration has been given to the elimination of wear in this part of the machine, as any backlash would have a detrimental effect on the lead and thickness of the threads. The indexing is entirely automatic and exceptionally accurate; a device is embodied which prevents over-run, and worms with either long or short lead can be ground with equal accuracy. The index gears are arranged so that no intermediate gears are necessary.

At the end of each stroke of the work table, forward or return dog clutches are engaged by an automatic trip mechanism which can be set to suit the length of the worm being ground.

A suitable fixture is provided whereby the face of the wheel can be trued by means of a diamond which is traversed across the wheel in a fixed plane.

The machine has a 3 ft 4½ in. length capacity between centres and will grind worms up to 10 in. diameter, and up to 20 in. face width. With the standard leadscrew, the maximum lead that can be ground is 40 in.

THE INVOLUTE HELICOID. Descriptive illustrated notes will be found in Chapter XVI.

CHURCHILL THREAD-GRINDING MACHINES. These machines are manufactured by the Churchill Machine Tool Co., Ltd., of Broadheath, near Manchester, well-known makers of grinding machines of various types. In conjunction with various Churchill grinding machines thermionic valves are employed. On the thread-grinding machine the workhead motor is driven at the working speed in a forward direction, the table being returned at a fixed high speed to its starting point. By a variation of the Ward-Leonard principle, the speed of the workhead is controlled, but the d.c. supply is from a mercury-arc rectifier. Details are obtainable from the makers and it suffices for our purpose to say that the induction regulator incorporated in the design provides a very smooth variation in the speeds obtainable, i.e. without definite

"steps." When the workhead armature motor is reversed, the motor is caused to run at top speed in the reverse direction. One large valve is employed in the system, and not a number of small ones.

THE JONES AND LAMSON AUTOMATIC THREAD-GRINDING MACHINES. These are made by the Jones and Lamson Machine Company, Springfield, Vermont, U.S.A., a firm with long experience in the design and manufacture of thread-grinding machines.

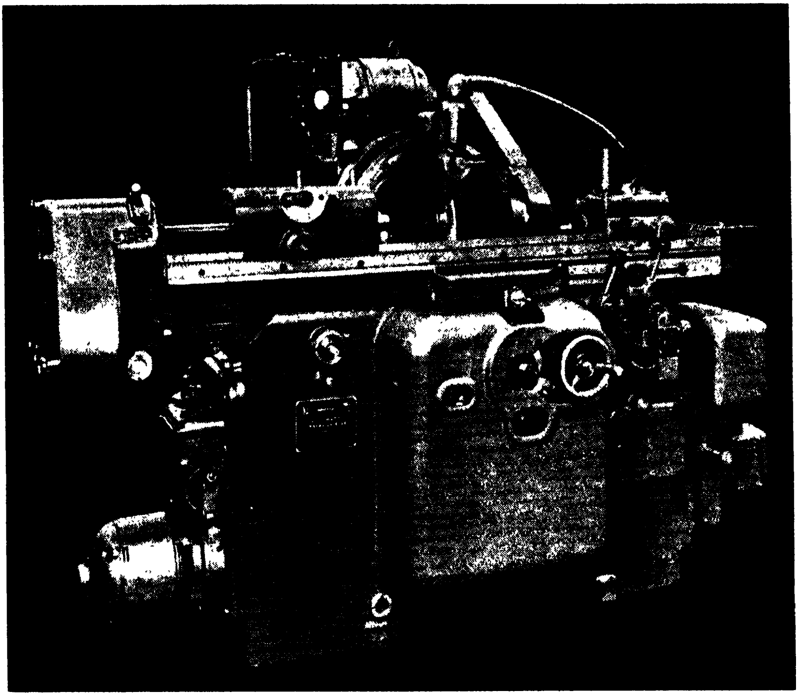


FIG. 7. A TYPICAL JONES AND LAMSON THREAD-GRINDING MACHINE

A popular machine in their series is the "6 × 36" Automatic Universal Thread Grinder for producing accurate threads, either internal or external, at minimum cost. Some features of the "J. & L." machines are, briefly, as follows.

The machines are fully automatic in operation and do not require a high degree of skill in operating, inasmuch as attention has been given to making all controls under the influence of the machine operator as foolproof as possible. The "J. & L." method of controlling thread-grinding wheel speeds is unique and original. The automatic wheel-truing device is equipped with a scale which automatically records the wheel diameter. A chart on the wheel slide tells the surface speed of the wheel in feet per minute based on the wheel diameter, and its r.p.m., as indicated by the rheostat pointer.

This rheostat permits the operator to get the desired wheel speed simply by turning the rheostat dial to the position specified on the wheel-speed chart, or, on the other hand, readily allows of an infinitely variable wheel speed without any "belt-and-pulley" changes. Thus the best wheel speed is obtained quite easily

The grinding wheel used is of the single-rib type—20 in. diameter by $\frac{3}{8}$ in. wide. It is a standard wheel which may be used until it has worn to about $15\frac{1}{2}$ in. diameter.

The fully automatic wheel-dressing unit operates at the rear of the wheel and eliminates "idle dressing time," as the wheel may be re-trued

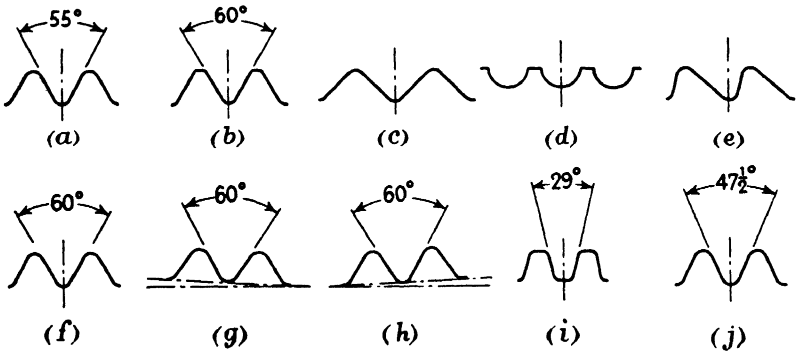


FIG. 8. THREAD FORMS OBTAINABLE WITH PANTOGRAPH TRUING DEVICE ON A "J. & L." MACHINE

Each different Form, Pitch, or Taper requires a different set of Formers.

(a) Whitworth form.
(b) Flat top and round bottom.
(c) Special form.
(d) Special form.
(e) Buttress round top and bottom.
(f) A. P. I. thread straight.
(g) A. P. I. tapered. For taps and chasers, for collapsible taps.
(h) A. P. I. tapered. For grinding pipe and gauges.
(i) Worm threads with radii on corners.
(j) British Association Standard.

periodically while the work traverse is on the return stroke. An electrical-mechanical arrangement controls the truing cycle and may be set to dress the wheel automatically after each roughing cut, or any individual cut, and before, or after, the finishing cut. There is automatic compensation for the reduction in wheel diameter due to the wheel-truing operation.

One-way and two-way grinding is carried out without any reduction of the automatic cycle of operations. The wheel is automatically backed away from the work at the end of the cutting stroke on one-way grinding.

It is customary practice to use two wheel-dressing and truing units, one being a Pantograph type and the other a Universal type. The former of these is used for producing a thread form with a controlled radius at top and/or bottom. The latter is used for producing any straight flanked thread or gear form with a parallel, tapered, and/or chamfered crest and root.

Typical forms produced by using the Pantograph and the Universal

truing device are shown in Figs. 8 and 9 (by permission of the Jones and Lamson Machine Company).

The capacity of the "6 × 36" machine is: work length 36 in., thread length 12 in., work diameter $7\frac{1}{2}$ in., and the maximum thread diameter is $6\frac{1}{2}$ in. A 12 in. length of thread can be ground anywhere along a 24 in. work length.

The "12 × 45" machine will grind a thread up to 12 in. diameter with a maximum work diameter of 12 in.—the length between centres (max.) is 45 in.

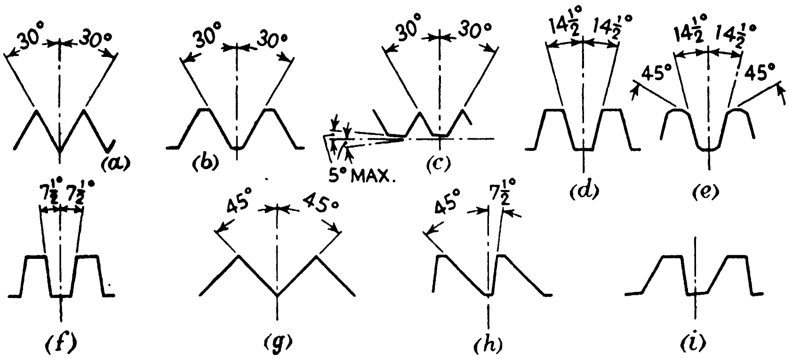


FIG. 9. THREAD FORMS OBTAINABLE WITH UNIVERSAL TRUING DEVICE ON A "J. & L." MACHINE

(a) 2–30° formers required for any 60° thread form not using the back diamond.
(b) 2–30° formers using back diamond for root form.
(c) 2–30° formers using back diamond adjustment for sloping root forms.
(Thread forms shown in (a), (b) and (c) can all be ground with the same set of 30° standard formers.)
(d) 1 set of standard $14\frac{1}{2}$° formers will grind any 29° thread form, 2 pitch or finer.
(e) Special formers are required for each different pitch or chamfer specification.
(f) 1 set of $7\frac{1}{2}$° formers will grind any 15° included angle thread form with depth not exceeding $\frac{1}{8}$".
(g) 1 set of 45° formers will grind any 90° thread form, 2 pitch or finer.
(h) 1 set of (1) $7\frac{1}{2}$° and (1) 45° formers will grind any $7\frac{1}{2}$° × 45° buttress thread, 2 pitch or finer.
(i) With suitable formers it is possible to grind straight-sided threads either symmetrical or buttress of any included angle from 15 to 90 degrees inclusive.

The machines are mounted on three-point bearings so that it is not necessary to work for correct alignment.

The makers can supply a *thread-relieving unit* for form-relieving on the whole of the thread form or the outside diameter only. Interrupted threads may also be ground. A hob-grinding unit is readily mounted for grinding hobs, cutters, etc., with annular grooves with or without relief and/or taper.

The maximum helix setting of the wheelhead is 25° left-hand, and 30° right-hand, so that the machine readily lends itself to the grinding of broaches, helical splines, multi-start threads, and similar work of steep helix. Sales and service agents in England are Messrs. Charles Churchill & Co., Ltd., Birmingham.

EX-CELL-O THREAD-GRINDING MACHINES. These are made by the Ex-Cell-O Corporation of Detroit, Michigan, U.S.A. In these

descriptive notes we refer especially to two widely-used models, viz. style 39 (A and L, both automatic) and style 35 (with 35L).

Fig. 10 shows style 39A, Internal Precision Thread Grinder. This is identical with style 39L, except that the latter is equipped with an auxiliary slide between the work spindle and grinding spindle to support a steady-rest, so as to enable it to handle longer workpieces.

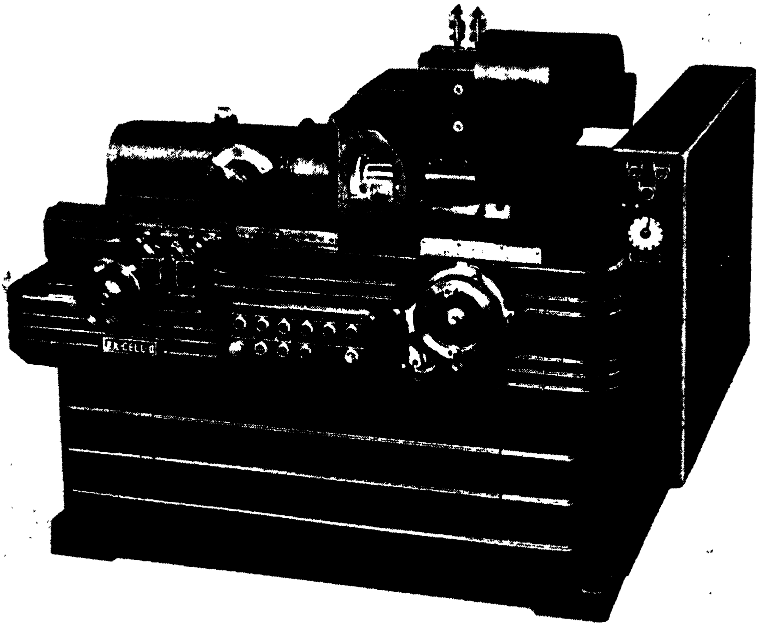


FIG. 10. EX-CELL-O PRECISION THREAD GRINDER

A reversible electric motor imparts a hydraulically-controlled movement to the work spindle.

Changes in pitch, or lead, are readily obtained by mounting interchangeable lead-screw and nut assemblies, and provision is made for matching up pre-cut threads by means of a lead pick-up mechanism which is hand-operated. The grinding spindle is mounted on a hydraulically-operated cross-slide for indexing on the forward and return grinding stroke.

The flow of coolant can be fed through the inside of the work spindle, and is automatically stopped for loading and unloading the work parts to be ground.

On the style 39L the distance the thread can be ground from the face of the flange type nose on the work spindle is 2 in. to 44 in.

Other models in the Ex-Cell-O range are the styles 31 and 31L;

the 33 and 33L Automatic; and the 35 and 35L Universal. Some brief notes on the last-named machines follow.

Style 35 and 35L. The machine table carries the work spindle and adjustable tailstock, and is moved longitudinally on the machine bed, on anti-friction rollers, by a lead screw, which is driven by a train of gears connected to the work spindle. Various pitches are obtainable by change gears. The upper part of the table may be swivelled for taper grinding.

A hydraulic backlash compensator operates in conjunction with the lead screw to enable grinding to be done in both directions of table traverse and to reverse automatically at the end of the table traverse. By means of a built-in mechanism pre-cut threads may readily be matched up with the grinding wheel.

For grinding odd pitches or for obtaining very accurate lead dimensions, the setting obtained with the train of gears may be varied the desired amount, as shown by a graduated control, and then locked in position.

Style 35 will grind to a predetermined size and then stop automatically, or it may be set to stop at either end of the table travel. The cross-feed provides hand or automatic feed, and the grinding wheel may be dressed manually or automatically.

Some of the many interesting details are: Maximum diameter of external thread ground with 18-in. wheel is 8 in. (with 14-in. wheel is 12 in.); maximum swing is $14\frac{3}{4}$ in.; maximum threaded length with style 35 is 22 in., with 35L, 36 in.; maximum helix angle setting (both models) is 45° left-hand and 30° right-hand. Internal threads are: maximum diameter, 8 in.; maximum length, 3 in.

Extra standard equipment includes a refrigerator-type oil-cooling unit driven by a thermostatically-controlled electric motor; a suction hood, to prevent coolant vapour diffusement, with in-built fan and oil-reclaiming filter; a cam grinder for producing all standard and non-standard form cams from large-size straight-form templates; a work-table extension to permit workpieces up to 72 in. to be ground; and a headstock centre-grinding attachment.

INSTALLATION OF THREAD-GRINDING MACHINES. The installation of expensive special-purpose machinery should be undertaken in close accordance with instructions issued by the manufacturers. For instance, some makers advise against "grouting in." Whatever the make of machine, however, there are certain general principles to be followed, and it may not be inopportune to mention the more important of them.

The first essentials, if satisfactory machine performance is to be obtained, are that the grinder must have **a solid foundation** and that its principal slides, etc., must be level. The best foundation is a solid concrete floor, the depth of concrete depending upon the nature of the sub-soil. A 12-in. depth of concrete is generally suitable. If the machine is to rest on a wooden floor it is essential that the floor be

rigid, i.e. free from vibration. In some cases machines have to be installed in upper floors, galleries, or balconies, and in such cases they should be placed as close as possible to walls, pillars, or columns. On some machines silent block mountings are assembled into the base, so as to absorb a reasonable amount of vibration.

Sufficient room should be left between the grinder and surrounding machines to permit easy access to front, back, and sides, and especially to allow of ready manipulation of the wheel-dressing equipment and easy cleaning of the coolant tank.

Levelling is important. On the Ex-Cell-O Precision Thread Grinder, for instance, three foundation rest pads and bolt holes are provided at the bottom of the base of the machine. This three-point contact with the floor allows the machine to settle firmly and also provides a convenient means for levelling. A good quality machinist's level should be employed. It should be placed on the table ways of the machine alternately in a line with its main axis and at right angles to it. When using the level it is essential to give the bubble time to come to rest. Hasty levelling is useless. Wooden wedges should never be used for the levelling of precision machinery; steel is the best material.

During the levelling process it is important to see that no one exerts force on any of the spindles, or hammers the machine. Similarly, precautions must be taken if the machine is slung to see that lifting ropes do not bind against any part of the machine where undue force or leverage would cause damage. Spindles mounted in lapped and closely-fitted precision ball-bearing races can easily be damaged by thoughtless handling during the installation of a machine.

SIMPLE PRACTICAL HINTS TO OPERATORS. From a study of other chapters in this book it will be evident that there are many points in thread grinding which deserve careful attention. To attain maximum efficiency, all factors which are under the control of the operator must work harmoniously and efficiently. For instance, the selection of the abrasive wheel is quite an important item, so also is the wheel/work speed ratio and depth of cut.

Assuming that due attention has been given to these points, there still remains the *machine performance* factor. The performance of any machine is directly proportional to the effectiveness of its system of lubrication. Therefore careful attention should always be focused upon this very important factor. The instructions of the manufacturer should be adhered to in detail. Before starting the machine, it should be ascertained that all units are correctly lubricated, that oil-gauges function correctly, and that the type of lubricant being used is in accord with specifications of the manufacturer of the grinding machine.

Periodical inspection should be carried out with particular attention to electric motors, bearings, belt drives, and geared transmission.

During the designing of any machine, careful thought is given to making all moving parts of it as foolproof as possible. Many units are so designed that they are tamper-proof. Even so, occasion can, and

does, arise when it is very easy to cause much damage simply by pressing the wrong push-button or by operating the wrong lever.

When confronted by a thread-grinding machine for the first time one may be allowed a feeling of bewilderment which the sight of so many levers, hand-wheels, push-buttons, and other machine controls engenders. The experienced operator would not attempt to "get on with the job" before he had studied the "Operators' Handbook of Instructions." The value of so doing may be gauged from the fact that a machine may cost about £5000, yet in a thoughtless mood the operator may do it almost irreparable damage.

Manufacturers of all leading thread-grinding machines issue comprehensive well-illustrated Operators' Handbooks. These are compiled for the use of machine operators, and foremen should see that they are available to them. The most efficient operator is the man who has, by study of the makers' handbook, gained sound knowledge of the design and capacity of the machine, of the purpose of the various controls, and so on. One well-known demonstrator insists on explaining how to *stop* the machine *before* showing how to start it.

When cleaning the machine "ways" a soft cloth should be used; "waste" leaves lint in its path. An air-pump should not be used, because dirt, oil, and abrasive dust may be blown into the "ways" and bearings of the machine—as well as into the eyes of the operator. The electrical controls should be kept free from grease and oil.

Belts and pulleys must be kept dry and the tension should be adjusted when wear and stretching has taken place. Wear of vee belts is accelerated if the pulleys are not in true alignment.

CHAPTER III

GRINDING METHODS

THERE are four* types of thread grinding in general use, viz.

(1) Single-rib wheel grinding (Single-Rib Method).
(2) Dual-rib wheel grinding (Dual-Rib Method).
(3) Multi-rib wheel plunge grinding (Multi-Rib Plunge-Cut Method).
(4) Multi-rib wheel traverse grinding (Multi-Rib Traverse Method).

All these methods have their own particular advantages and the choice of which one of them is most suitable for any given job depends upon conditions peculiar to the equipment used, the degree of accuracy required, the material to be ground, the method of wheel dressing, the shape of the workparts, and the time factor.

Some of the thread-grinding machines, e.g. "Jones and Lamson," are designed solely for using single-rib wheels. As will be realized after subsequent paragraphs have been read, it has been the policy, in the design of these particular machines, to devote a great deal of attention to the provision of highly-efficient automatic and quick-action mechanisms for diamond dressing of the abrasive wheels. Of the other thread-grinding machines some are adaptable for using any of the four methods mentioned above. Whatever the design of a thread-grinding machine, its final usefulness depends very largely on the efficiency of its dressing device.

(1) **SINGLE-RIB METHOD.** The advantages of a single-rib wheel in comparison with a multi-rib wheel are as follows—

(*a*) Due to the fact that only one complete thread ridge has to be formed on the periphery of the abrasive wheel, it is obvious that more scope is available in the design of the wheel-truing mechanism. This results in the operation of wheel forming being accomplished conveniently and rapidly. The setting-up time for this method is usually small.

(*b*) The area of contact between the wheel and the product is, in comparison with other methods, very small, being restricted to the single-thread ridge of the abrasive wheel and one space in the work. Thus less heat and friction is encountered. The latter factor allows the use of higher grinding speeds and deeper cuts.

Useful Hints to Operators. Where the shape of the work will allow the wheel to pass over more than the entire length of the thread to be ground it is advisable to taper the leading edge of the wheel, as shown in Fig. 11. About 3° taper will suffice with a fair-sized radius on the edge of the wheel. This leading edge of the wheel will then remove the bulk of the surplus material on the work and save needless wear of the thread ridge on the face of the wheel. Where, however, the thread

* *Centreless thread grinding* is now being developed intensively in England (the Herbert Scrivener machines are now marketed by Alfred Herbert, Ltd.) and in the U.S.A. the Landis Tool Co. machines have had wide publicity.

finishes adjacent to a shoulder it becomes necessary to dress the leading edge of the wheel with sufficient clearance to allow a complete section of thread to be ground right up to the undercut. See Fig. 12.

When grinding American and similar forms of threads with flat crests it is standard practice to use a wheel which is dressed, by means of diamond tools, with a form which is wholly the extended section of the thread groove, as shown in Fig. 13 (*b*). To avoid needless wear of the diamond tools it is recommended that the portion of the wheel

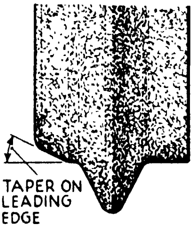


FIG. 11. SINGLE-RIB WHEEL WITH TAPER ON LEADING EDGE

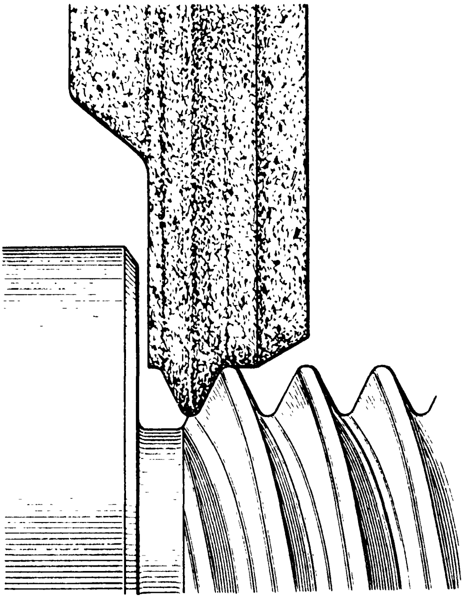


FIG. 12. SINGLE-RIB WHEEL CUT AWAY TO PERMIT GRINDING THREAD CLOSE TO SHOULDER

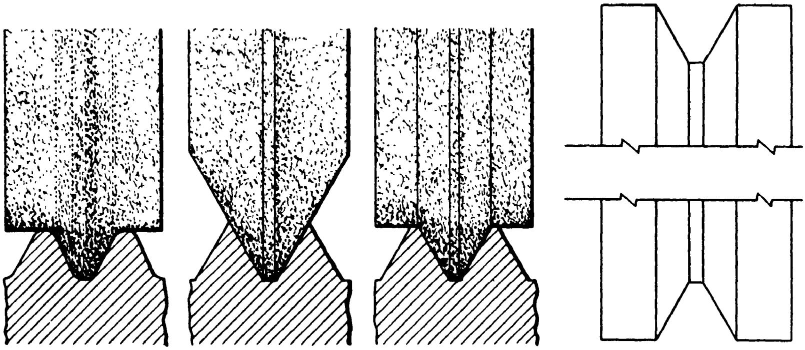
which is not used in actually grinding the thread be relieved as shown in Fig. 14. Of course, the crests of the threads cannot be ground with a wheel formed in this manner and so it becomes necessary to grind the crests in a separate operation. For this purpose a flat-faced wheel is used, as shown in Fig. 15, which grinds the crest to the required width-of-flat. At the same time the major diameter is also ground to the required size.

When, however, the wheel is formed by means of a crushing roller the form of the thread ridge on the wheel is a replica of the complete section of the thread to be ground on the product—not an extended section as is the case when diamond tools are used for forming the wheel. The form of the thread groove on the crusher is the same as the form of thread to be ground on the workpart. Thus the *crushed* wheel will grind the *complete thread* on the workpart, i.e. the flanks, the flat roots, and the crests. See Fig. 16. A single-rib wheel with a

crushed form is shown in Fig. 13 (*c*). This enables the complete form of thread to be ground in one operation. Obviously, then, one advantage of using crushing rollers when dealing with flat-crested threads lies in the fact that the otherwise separate operation of grinding the crests and, incidentally the major diameter, is eliminated.

Profile Crushing of Single-rib Wheels. Only when the wheel spindle and its assembly is so designed and proportioned that it can safely withstand the thrusts set up by the pressure of the crushing roller, should profile crushing of single-rib wheels be employed.

Generally it will be found that single-rib wheels are dressed to form



(*a*) (*b*) (*c*) (*d*)

FIG. 13. SINGLE-RIB WHEELS

(*a*) Wheel formed for thread with controlled radius.
(*b*) Wheel formed with diamond tools for American type of thread.
(*c*) Wheel formed with crushing roller for American type of thread.
(*d*) Crushing roller for wheel shown at (*c*).

by means of diamond tools, whilst multi-rib wheels are formed either with diamond tools or with crushing rollers.

Plunge Grinding. With single-rib wheels plunge grinding is practicable only in the grinding of annular grooves such as are required on disc-type cutters, thread-milling hobs, and crushing rollers. Plunge grinding is characteristically a multi-rib wheel method.

(2) **DUAL-RIB METHOD.** Dual-rib wheels have certain characteristics similar to those of single-rib wheels. They are successfully used for grinding coarse pitch and two-start threads. However, there are definite limitations to their use for grinding threads of very steep helix, due to the inherent helical interference. The latter item increases in importance with the higher degrees of accuracy that may be required.

Generally speaking, the use of standard diamond-dressing equipment suffers some restrictions in adaptation for dressing a dual-rib wheel—often referred to as a "twin-ribbed wheel." As a result of this difficulty a *crushing roller* is often used. A typical dual-rib wheel is shown in Fig. 17.

One advantage of using this type of wheel for grinding single-start

threads is that the leading ridge on the wheel can be formed for the purpose of roughing-out the thread, whilst the following ridge can be used for the finish cut.

(3) MULTI-RIB METHOD—PLUNGE GRINDING. The abrasive wheel is formed with a series of thread-form *annular* grooves which

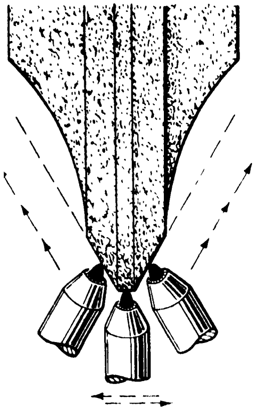


FIG. 14. SINGLE-RIB WHEEL THINNED TO AVOID NEEDLESS WEAR OF DIAMONDS

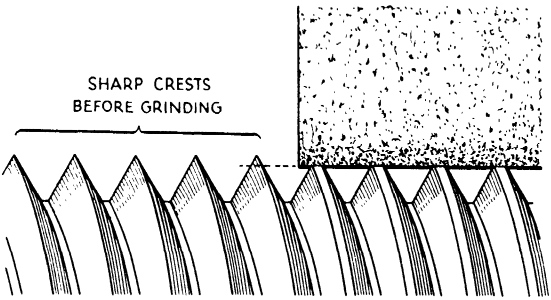


FIG. 15. USING FLAT-FACED WHEEL FOR GRINDING CRESTS OF AMERICAN TYPE OF THREAD

usually extend across the whole face-width of the wheel, as shown in Fig. 18. Where, however, the length of thread on the workpart is considerably less than the face-width of the wheel it is recommended

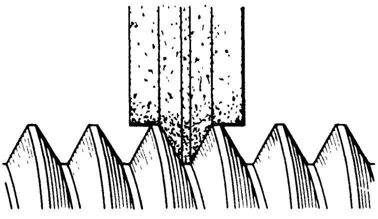


FIG. 16. CRUSHED WHEEL GRINDING A COMPLETE THREAD FORM

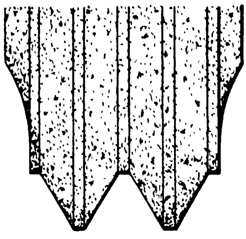


FIG. 17. DUAL-RIB WHEEL

that that part of the wheel which is not used for the actual grinding should be dressed away to avoid needless wear of the wheel-forming tool. It is a good rule to restrict the number of thread ridges on the wheel so that the working face-width of the wheel is greater than the length of thread on the workpart by about two or three times the pitch.

At the starting position (Fig. 19 (*b*)) the headstock and tailstock units are so positioned that the workpart is directly in front of the abrasive wheel. The wheel is "plunged" radially into the workpart

as the latter commences its rotation and axial traverse. The "plunging," or in-feed, to an amount equal to the correct depth of thread, takes place during approximately one-third of a revolution of the work. The grinding to size takes place in approximately one further complete revolution.

While the work is rotating it also receives an axial traverse so that the helix having the appropriate thread form is ground into its surface. If the length of thread to be ground is less than the face-width of the abrasive wheel, then the complete thread is ground during about one and one-third revolutions and one and one-third pitch-length of work traverse. When the length of thread to be ground exceeds the face-width of the wheel it is necessary to use a correspondingly longer

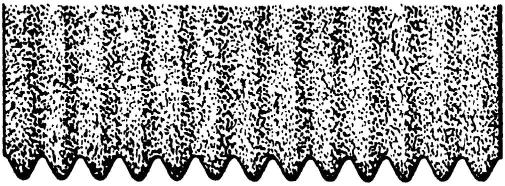


FIG. 18. MULTI-RIB WHEEL

length of work traverse. In the latter case the operation is really a combination of the "plunge-cut" and the "traverse-grinding" methods. Abrasive wheels up to about 2 in. face-width are frequently used. Thus the plunge-cut method is speedy. However, plunge grinding is a heavy-duty method, from which it follows that it is not always accompanied by a high degree of accuracy in the product.

Tilting the Grinding Wheel. Another cause of inaccuracy in thread grinding arises from the fact that it is usual to tilt the grinding wheel to the helix angle of the thread in the workpiece. Under these conditions it is incapable of producing a truly exact form of thread except at the point where the axis of the wheel crosses the axis of the work in the horizontal plane. This was pointed out in an informative article on thread grinding prepared by the Tool Technical Panel of the Diamond Die and Tool Control of the Ministry of Supply, published in *Aircraft Production*, June, 1942. In that article it was also emphasized that there is an accompanying slight constant pitch error, as well as a form error which becomes progressively larger as the distance from the meeting point of the axes of wheel and work increases. However, both these errors can be corrected by adapting the form-dressing mechanism to produce a compensated form in the wheel.

(4) MULTI-RIB METHOD—TRAVERSE GRINDING. One difference between plunge grinding and traverse grinding, revealed by a glance at Fig. 19, lies in the difference between the relative positions occupied by the abrasive wheel and the workpart at the respective "starting positions." Another difference is in the respective lengths of the work traverse. In the traverse grinding method (sometimes called the "straightover "method) the abrasive wheel is not plunged radially into the workpart, the latter being so located at the "starting position" that its leading edge or front lies immediately at the left of

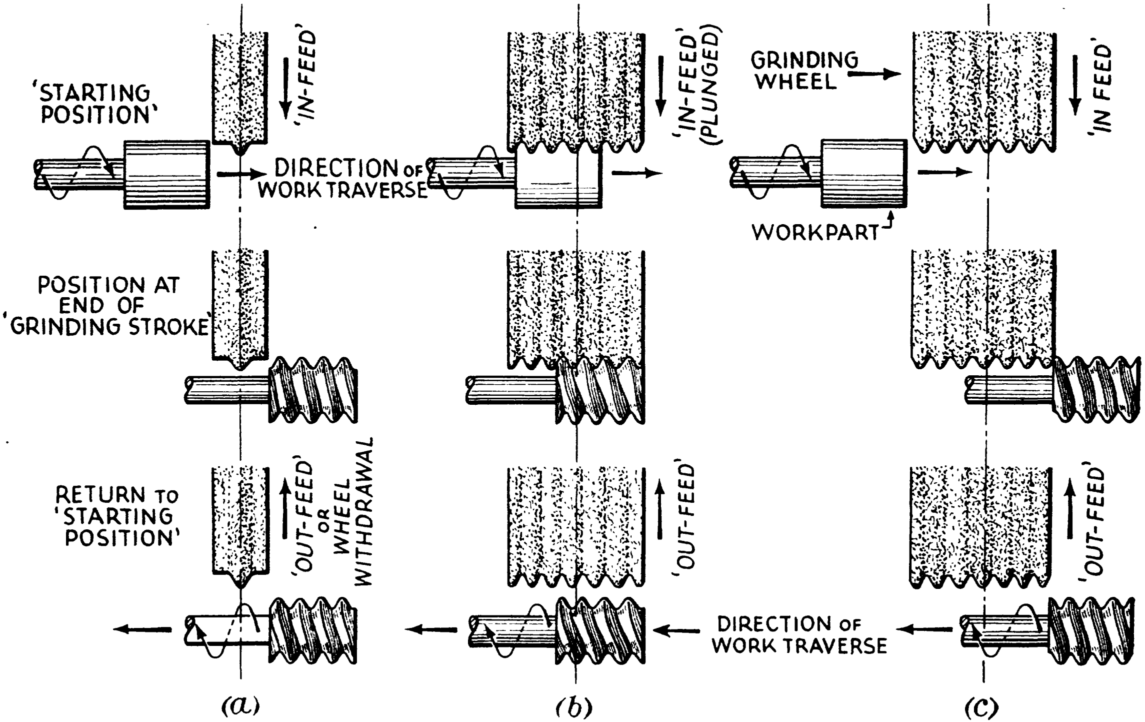


FIG. 19. GRINDING METHODS

(*a*) Single-rib Method. (*b*) Multi-rib Plunge Cut Method. (*c*) Multi-rib Traverse Method.

All three examples are of right-hand threads ground by the one-way directional grinding method. Arrows show direction of work traverse for R.H. threads. For L.H. threads the directions of work rotation would be reversed. See notes in this Chapter on *Comparison of Grinding Methods* and *The Principal Movements of the Thread-grinding Machine.*

the leading edge of the wheel. See Fig. 19 (c). Thus, at the moment when in-feed of the wheel commences, the wheel does not make contact with the work. In plunge grinding, however, the wheel is plunged, or fed, directly into the workpart.

At the "starting position" in traverse grinding, as shown in Fig. 19 (c), the wheel is fed inwards, i.e. towards the axis of headstock and tailstock, the amount of in-feed being dependent on the depth of cut to be taken and the diameter of the thread to be ground. The wheel approaches the axis of the workpart as the latter commences its rotation and its traverse towards the leading edge of the wheel, these motions of the workpart continuing until the complete thread has been ground. This stage having been reached, the wheel is withdrawn from

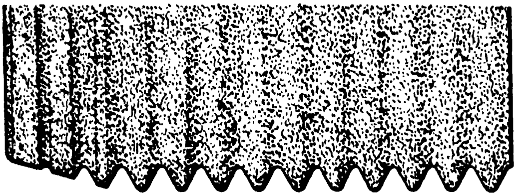


FIG. 20. MULTI-RIB WHEEL WITH TAPER ON LEADING EDGE

the workpart, the latter meanwhile reversing its direction of rotation and of traverse and so returning to the "starting position." Where more than one cut is necessary the cycle of operations is repeated until the thread is ground to the required size and to the desired quality of surface finish.

Where there is no shoulder to foul the passing of the workpart across the whole face-width of the wheel it is practicable to obtain a very high degree of accuracy in the product. Multi-rib traverse grinding is employed for grinding thread gauges, gear-cutting hobs, and similar work carrying precise limits in regard to diameter, pitch, form, and surface finish. The minimum length of work traverse needed to enable this method to operate is equal to the face-width of the wheel, plus the length of threading on the workpart.

The difference between traverse grinding by the multi-rib and single-rib methods lies simply in the fact that in the former a multi-rib wheel is used, whereas in the latter a single-rib wheel is used. Due to the fact that some error, however minute, may be present in the spacing and parallelism of the thread ridges formed on a multi-rib wheel it is fair to state that, other things being equal, a higher degree of accuracy is normally obtainable with a single-rib wheel. However, many factors enter into a precision grinding operation and we should add that some experts contend that by and large it is generally easier to produce an accurate product with a multi-rib wheel than with a single-rib wheel. The authors prefer a single-rib wheel for gauge grinding where extreme precision is called for.

Where the shape of the workpart permits it to pass across the whole

face-width of the wheel it is advantageous to taper the leading edge of the wheel as shown in Fig. 20. This enables the leading edge to perform a roughing-out operation—an advantage when grinding troublesome work requiring many cuts. It is also conducive to longer life of the full-form ridges of the wheel.

COMPARISON OF GRINDING METHODS. In (*a*), (*b*), and (*c*) in Fig. 19 the uppermost three diagrams, from left to right, show relative positions of the grinding wheel and workpart at the "starting position." All examples refer to right-hand threads ground by the *one-way directional grinding method* explained later in this chapter. Note that at the "starting position" the wheel is fed radially towards the axis of the workpart as the latter commences rotation and axial traverse.

The middle three diagrams show relative positions at the end of the "grinding stroke," i.e. when the thread has been ground completely.

The bottom three diagrams show the reversal of work rotation, the reversal of work traverse, and the backing away of the wheel radially from the axis of the workpart.

(*a*) **Single-rib Method.** Sequence of operations—

(1) The grinding wheel is fed towards the axis of the workpart as the latter commences rotation and traverse.

(2) The thread is ground as the workpart rotates and traverses across the face of the wheel.

(3) The grinding wheel is withdrawn from the workpart at the end of the "grinding stroke."

(4) The workpart momentarily pauses, then reverses its directions of rotation and traverse, so returning to "starting position."

(*b*) **Plunge-cut Method.** Sequence of operations—

(1) The grinding wheel is fed radially and directly *into* the workpart as the latter commences rotation and traverse. Note that at the "starting position" the work is in contact with the wheel. Therefore the work need only make one complete rotation and one pitch length of traverse to enable the complete thread to be ground.

(2) The work having reached "the position at end of grinding" the wheel is backed away from it.

(3) The work momentarily pauses, reverses its directions of rotation and traverse, and so returns to the "starting position."

(*c*) **Traverse-grinding Method.** Sequence of operations—

(1) The grinding wheel is fed radially towards the extended axis of the workpart as the latter commences rotation and traverse. See the diagram, noting that the wheel does *not* contact the work at this stage.

(2) The work continues rotation and traverse, moving towards the wheel.

(3) The work reaches the grinding wheel and thread grinding takes place as the work rotates and traverses across the whole face-width of the wheel.

(4) The work having reached the "position at end of grinding," it momentarily pauses while the wheel is withdrawn. The work then reverses its directions of rotation and traverse and so returns to "starting position."

THE TWO "DIRECTIONAL" GRINDING METHODS. "One-way" and "two-way" are terms used to describe two kinds of "directional grinding" by means of any of the four types of abrasive wheel previously referred to.

One-way Grinding. In this method the wheel is fed into the work, the thread being ground while the revolving work travels in one direction only. When the wheel reaches the end of the thread it is backed

away from the work and the latter is returned to its primary position. No grinding takes place on the return stroke, during which the work reverses its direction of rotation and of axial traverse.

Two-way Grinding. When the wheel reaches the end of the thread it is not backed away from the work, but continues to grind the thread on the return stroke. Between the two strokes the work pauses momentarily, after which it reverses its direction of traverse and rotation. Thus there is no idle time.

The two-way method is used mainly in mass-production of workparts which do not need grinding to precisely close limits.

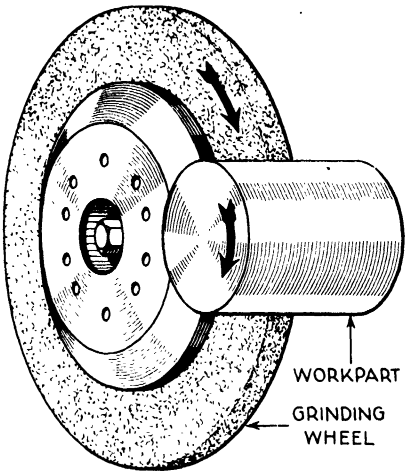


FIG. 21. DIRECTION OF ROTATION
(Plain cylindrical grinding.)

DIRECTIONS OF ROTATION AND TRAVERSE

(1) **Direction of Wheel Rotation.** When viewed from the headstock end of the machine the grinding wheel rotates in a clockwise direction. This is shown in Fig. 21. Thus a thread-grinding wheel rotates in the same direction as the grinding wheel of a plain cylindrical grinding machine.

(2) **Direction of Work Rotation and Traverse.** In plain cylindrical grinding it is customary to rotate the work in the same direction as the grinding wheel. (See Fig. 21.) Thus as the cutting surface of the wheel travels *downwards* it acts in opposition to the contact surface of the work which, of course, travels *upwards*. In plain cylindrical grinding the direction of rotation remains the same regardless of the direction in which the work travels axially. In thread grinding, however, the direction of work rotation must bear a distinct relation to the direction of axial traverse and it is this relation which determines the "hand" of the thread.

Referring to Fig. 22 (*a*), the direction of rotation of the grinding wheel, the direction of rotation of the work, and the direction of axial traverse of the work are shown for grinding a *right-hand thread.* When the workpart has traversed its whole threaded length across the grinding wheel, the latter is backed away from the work and the directions of rotation and traverse of the work are reversed, so that the work returns to its first position. Thus the work rotates in the same direction as the wheel while grinding takes place.

Fig. 22 (*b*) shows that, if the direction of rotation of the workpart is reversed, the thread produced will be *left-hand*, and that, during grinding, the work and the wheel rotate in opposite directions.

In *two-way grinding* the wheel is not backed away from the work at the end of the stroke, but the direction of work rotation and traverse is reversed and grinding takes place in both directions of axial traverse

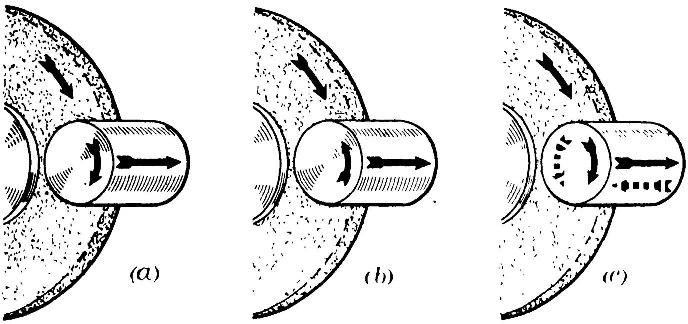


FIG. 22. DIRECTIONS OF ROTATION AND TRAVERSE IN THREAD GRINDING
(a) One-way Grinding, Right-hand Thread.
(b) One-way Grinding, Left-hand Thread.
(c) Two-way Grinding, Right-hand Thread.

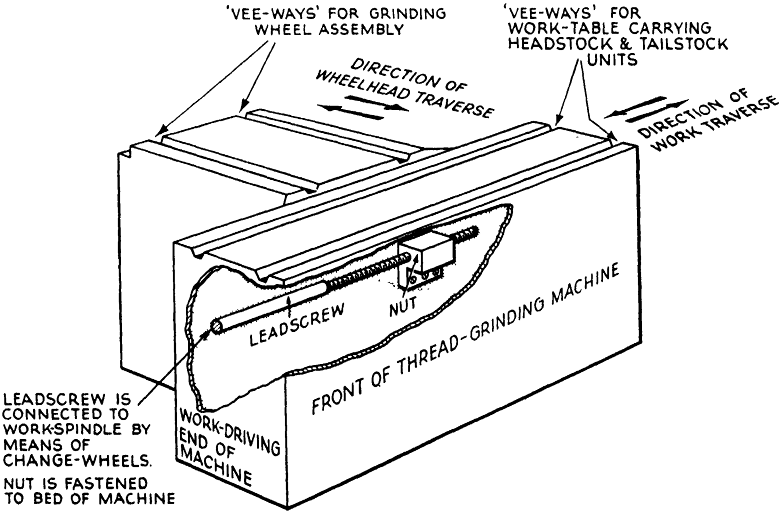


FIG. 23. THE PRINCIPAL VEE-WAYS OF A THREAD-GRINDING MACHINE
Wheelhead traverse is at right-angles to work traverse.

of the work. Therefore, in one direction of traverse the wheel rotates *with* the work and in the other direction of traverse it rotates *against* the work. See Fig. 22 (*c*), where "broken line arrows" show directions of work rotation and traverse when the workpart is returning to its original starting position.

PRINCIPAL MOVEMENTS OF THE THREAD-GRINDING MACHINE

The Movement of the Wheel. The grinding wheel, with its electric motor, is mounted on a base which can slide in a direction perpendicular to the line of centres of the headstock and tailstock units, such move-

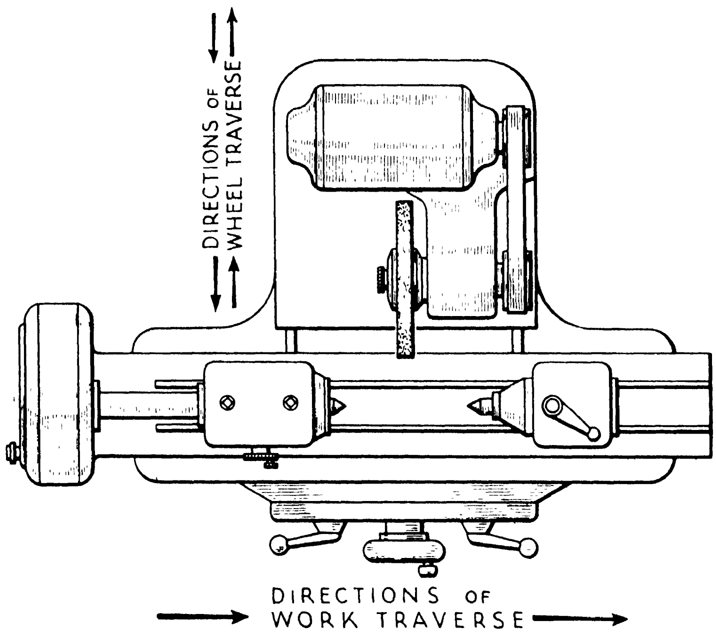


FIG. 24. PRINCIPAL MOVEMENTS ON A SIMPLE THREAD-GRINDING MACHINE

ment being controlled by means of an in-fed mechanism, such as the handwheel and screwed-spindle assembly.

Alternatively an automatic in-feed mechanism may be employed. *Thus the wheel may be fed into the work or away from the work.* Of course, the amount by which the wheel is fed towards the axis of the workpart controls the dimensions of the thread diameters produced on the latter. See Figs. 23 and 24.

The Movement of the Workpart. The headstock and tailstock units are mounted on a bed which can be traversed in a direction parallel to the axis of the grinding wheel by means of a train of gears connecting the work driving spindle with the leadscrew. Thus the rotary motion of the workpart is derived from the work driving spindle, whilst its axial traversing motion is derived from the leadscrew. See Figs. 23 and 24.

CHAPTER IV

MACHINE SETTING AND SEQUENCE OF OPERATIONS IN THREAD GRINDING

THIS chapter is, in the main, intended for readers who are directly concerned with the setting and operating of thread-grinding machines.

ESSENTIAL DATA. Before setting up a thread-grinding machine for any given job the following particulars must be known—

(1) The *pitch* and the *lead* of the thread.
(2) The *form* of the thread.
(3) The *hand* of the thread.
(4) Basic *diameters* and limit dimensions.
(5) Whether the thread is to be of standard parallel form, or whether it is to be *tapered*, *relieved*, *interrupted*, or is in any way to be of non-standard proportions or form.

The foregoing particulars comprise the minimum essential information necessary to enable all other related particulars to be determined—either by calculation or by reference to tables.

Included among additional particulars are—

(1) Helix angle or lead angle.
(2) Quality of surface finish.

SEQUENCE OF OPERATIONS. The actual sequence of operations adopted in individual cases depends upon such factors as the make of the machine, the type of work, and conditions peculiar to the shop and the job. However, the sequence usually adopted is given in the ensuing text.

CHANGE WHEELS. The first operation is to assemble a set of toothed spur wheels, or change wheels. The set selected must enable a correct ratio to be obtained between the speed of the lead screw and the speed of the work-driving spindle. Whilst in many instances it is possible to select the wheels by referring to the tables in the Operators' Handbook issued by the makers of the machine, it is necessary in other cases to calculate them. Examples of change-wheel calculations are given in Chapter X.

Care must be taken to see that change wheels are assembled in their correct relative positions and in such a way that trouble due to faulty assembly of wheels cannot arise while the machine is in use. It is advisable to allow about 0·005 in. backlash between mating gears so as to avoid jamming when under load.

SELECTING AND MOUNTING THE GRINDING WHEEL. Having assembled the change wheels the operator selects a grinding wheel and mounts it on the machine. See Chapter V for notes on Grinding Wheels.

The following elementary, yet important, practical hints should prove useful both to setters and operators—

(1) Clean away all grinding dust and cutting oil before assembling the grinding wheel, packing washers, and flange plates.

(2) Be sure that the grinding wheel is a free fit on the bore diameter register of the flange plate and that suitable packing washers are used.

(3) Carefully use an India oil-stone to remove any burrs and bruises that may have been caused in handling the flange plates.

(4) Tighten the securing screws with a pressure just sufficient to hold the grinding wheel firmly. Wheel distortion and fractures may result from severe or uneven clamping.

(5) Distribute the clamping pressure by tightening one screw and then tightening the screw farthest away from the screw already tightened, and so on.

(6) Mount the grinding wheel so that the makers' markings are in view when the wheel is mounted on the spindle.

(7) Test the wheel for cracks before and after it has been assembled.

(8) Allow the wheel to run at its operating speed for a few minutes, meanwhile standing well clear of the machine in case the wheel should break.

PRELIMINARY WHEEL TRUING. The grinding wheel is trued with a diamond tool as a preliminary to the wheel-balancing operation. It is unlikely that the wheel will be in balance or that it will run concentrically and without side "wobble." Its periphery is trued by taking light cuts across the whole of its face width and the "wobble" is rectified by taking many light cuts along its sides.

For this truing operation it is advisable to use heavy-duty diamond tools to withstand the hammering effect set up by the rough state of the wheel.

WHEEL REMOVAL. After the face and the sides of the grinding wheel have been trued, it is taken off the wheel spindle so that it may be tested and adjusted for running in proper balance.

When dismantling the wheel assembly from the machine, particular attention should be paid to the avoidance of damage to the wheel. Some "waste" or rags should be placed under it as a safeguard against "nicks" being caused if it should happen to slip. Such "nicks" are easily caused and result in shortening the life of the wheel as well as of the truing diamond. If the nick is but one-sixteenth of an inch in depth it becomes necessary to cut away one-eight of an inch from the diameter of the wheel.

WHEEL BALANCING. Much trouble arises in thread grinding due to the grinding wheel not being in balance. Generally the manufacturer of the grinding machine supplies a wheel-balancing unit, together with a mandrel and some balance weights. The balancing stand must be placed on a solid foundation, free from vibration, and should be adjusted so that the knife-edges or ground "ways" are perfectly level. It is essential that an accurate and sensitive level be employed.

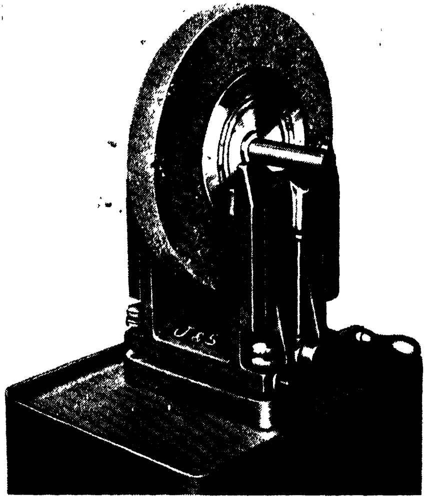


FIG. 25. PRECISION STATIC BALANCING UNIT

(*Courtesy of Messrs. A. A. Jones and Shipman*)

This consists of a cast-iron base with hardened and ground steel ways or edges. The wheel and wheel adapter are mounted on an arbor, the latter being laid across the ways. Movable side shields protect the delicate steel ways. These shields can be raised slightly above the level of the ways to take the shock of loading, after which they are lowered by means of the handwheel, the work being deposited gently upon the ways. In this model a super-sensitive spirit level is incorporated in a levelling plate which can be laid across the ways.

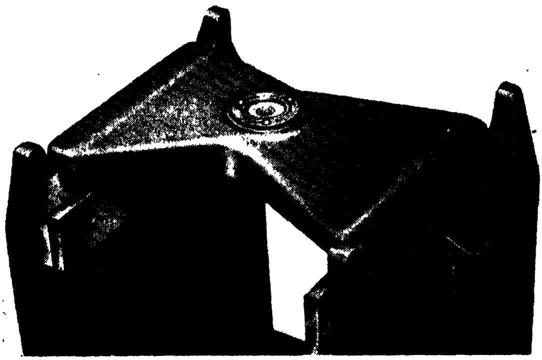


FIG. 26. LEVELLING PLATE IN POSITION ON WAYS

(*Courtesy of Messrs. A. A. Jones and Shipman*)

The knurled screws shown in Fig. 25 are manipulated until the bubble in the spirit level becomes concentric with the circle engraved on the glass. The adjusting screws are then locked and the levelling plate removed.

The grinding wheel is assembled on the mandrel and then placed on the balancing stand. The wheel will rotate to and fro until it comes to rest with its heavier part at the bottom. The light part is at the top and this is counterbalanced by attaching a balance weight to the uppermost part of the vee-way in the flange plate. The original balance of the wheel thus having been disturbed, it will again rotate to and fro and then come to rest. At this stage another balance weight is added to the second light part of the wheel and the process repeated by adding further balance weights or by altering the positions of weights already attached.

The wheel is in perfect static balance when it remains stationary in any position along the runways of the balancing stand.

Particular note should be taken of the following point. Should the grinding wheel be a loose fit in the bore diameter it may easily be mounted eccentrically, and during the preliminary wheel-dressing a varying amount will be dressed from its periphery. In such a case the wheel would be out of balance after the preliminary dressing although it may possibly have been in balance originally.

While the machine is out of use, the cutting oil absorbed by the wheel gradually sinks to its lowest part—thus throwing it out of balance. Hence it becomes necessary to re-balance the wheel occasionally.

After the wheel has been balanced it is again mounted on the grinding machine and given a light dressing with a sharp-pointed diamond tool. The wheel is then formed with ridges having the appropriate form of thread. The latter operation is dealt with in Chapter VIII.

HELIX ANGLE SETTING. Usually the wheelhead housing is swivelled over to the helix angle of the thread required on the work-part. A scale attached to the wheelhead shows the angle to which the wheel is tilted. This angle is usually called the *helix angle* on screw threads and *lead angle* on worm threads. In the case of the Newall range of machines the worktable, and not the wheelhead, is swivelled to the helix angle of the thread.

Notes on the terms *helix angle*, *lead angle*, and *spiral angle* are given in Chapter XVI. On ordinary screw-thread work, apart from worms, the term *helix angle* is used as shown in Fig. 117, and examination of which shows it to depend upon (1) the diameter of the work, and (2) the lead of the thread.

$$\text{Tangent of helix angle} = \frac{\text{lead of thread}}{\text{circumference of work}} = \frac{\text{lead}}{\pi \times \text{diameter}}$$

NOTES

(1) When the thread is single-start, pitch and lead are identical; when the thread is two-start, lead equals twice pitch; when the thread is three-start, lead equals three times pitch, and so on.

(2) The diameter (D) referred to above is the *mean diameter*, called the *simple effective diameter* on a screw thread, or the *pitch diameter* on a worm.

(3) Tables of helix and lead angles are given at the end of the book.

Lead Angles of Worms. The lead angle on a worm corresponds to the helix angle on an ordinary screw thread. See Chapter XVI and Fig. 120, where it is shown that on a worm the lead angle (λ) is the complement of the spiral angle (σ). This means that $\lambda + \sigma = 90°$. Thus, if the spiral angle is 82° 21′, the lead angle is 90° − 82° 21′ = 7° 39′.

In Fig. 120 and the relevant notes it is shown that, $\tan \lambda = \text{lead}/\pi \times$ diameter. Of course the value of π is indeterminate, but on most work of this kind it is satisfactory to take its value as 3·142, or as $\frac{22}{7}$.

EXAMPLE:

Single-start worm; pitch diameter 0·6418 in.; lead 0·0714 in.

$$\text{Tan of lead angle } (\lambda) = \frac{\text{lead}}{\pi \times \text{diameter}} = \frac{0{\cdot}0714}{\frac{22}{7} \times 0{\cdot}6418}$$

$$= \frac{7 \times 0{\cdot}0714}{22 \times 0{\cdot}6418} = 0{\cdot}0354$$

$\therefore$ Lead angle (from tables) $= 2°\ 2'$.

Mean Diameters. See full notes in Chapter XVI.

(1) On a standard screw thread the mean diameter is taken to mean its effective diameter, in other words it is equal to the "outside" diameter minus the full depth of a single thread.

(2) On a worm the mean diameter is generally taken to mean its pitch diameter, in other words it is equal to the outside diameter minus twice the addendum.

(3) On a gear-cutting hob the mean diameter is usually taken as the basic outside diameter minus twice the nominal dedendum.

POSITIONING COOLANT NOZZLES. It is worth reiterating that the coolant supply nozzles *must* be so positioned as to direct a flow of coolant to the area of contact between the wheel and the work. Trouble is bound to result otherwise, especially with increases in wheel speed and depth of cut. Flooding the work with coolant is not in itself sufficiently effective in thread grinding. Sufficient pressure is necessary to force the coolant between the crest of the grinding wheel and the groove of the thread. A simple general rule is to position the nozzle so that the shortest distance between the face of the wheel and that part of the nozzle bore which is farthest from the wheel equals the depth of the thread to be ground.

When dealing with work of coarse pitch and deep form, which involves high speeds, it sometimes becomes necessary to use a special form of nozzle. Furthermore, the regular supply of coolant may be supplemented by one or more additional nozzles, independently positioned to meet particular requirements.

OIL-SPLASH GUARDS. It is an advantage to be able to dispense with oil-splash guards, and sometimes this is possible by re-planning the positions of the coolant nozzles. Where guards have to be made to suit particular working conditions they should be designed with an eye to ease of fitting and handling. It is often found that a light guard of compact proportions, placed near the source of the splashing, serves the purpose admirably, indeed more conveniently than an unwieldy guard which covers much of the machine. When dealing with large quantities of workparts a great saving in time results from

the use of quick-acting guards, which may be collapsible, hinged, or telescopic in action. Larger guards should contain a transparent screen so that a clear view of the work can be obtained without the necessity of removing the entire guard. Glass, of course, is unsuitable, but perspex and similar materials are employed for this purpose satisfactorily.

POSITIONING THE HEADSTOCK AND TAILSTOCK UNITS. These units are positioned to suit the length of the workpart, but, like all sliding parts on these machines, they should not be moved until the mating ways and slides of the machine have been cleaned. When washing the "ways" the operator should make a practice of using clean rag—*not* "waste" (which leaves lint in the machine). After the ways have been washed they should be given a dressing of clean thin oil. This prevents rusting and is particularly essential when soluble cutting oils are used.

ARRANGING THE LENGTH OF TABLE TRAVERSE. The length of traverse of the worktable is controlled by adjustable limit stops or trip dogs. These stops are set so that the distance between them equals the desired traverse, the length of which for any job depends on (1) the length of thread to be ground, (2) the method of grinding. Thus in plunge-cut grinding the length of traverse is slightly greater than the pitch of the thread—provided that the width of the grinding wheel is greater than the length of threading.

A point to bear in mind is that stops should be so positioned that the difference between the length of table traverse and the length of the grinding traverse is as small as possible—so reducing idle traverse time to a minimum. See Fig. 81.

SELECTING THE WORK SPEED. First it must be stressed that no fixed general rules can be given for the selection of work speeds in thread grinding. The choice of the speed for any particular job depends on many factors peculiar to the machine, the operator, and the type of work. Data recorded from a survey of present-day thread-grinding practice enables a rough classification of work speeds into two classes, viz. fast and slow. See Table of Work Speeds on page 186.

Fast Speed. This speed range applies from about 160 to upwards of 450 inches per minute surface speed of the work.

It is axiomatic that the higher the speed of the work the lighter should be the depth of cut. Hence a fast work speed is employed when many light cuts are taken.

Slow Speed. This speed range applies from about one inch per minute to about 150 inches per minute surface speed of the work. A slow speed is employed when heavy cuts are taken.

We have mentioned that the selecton of a suitable work speed depends on various factors. Let us consider a few of these. See work speed references in Chapter XIII.

(1) **Arc of Contact.** Reference to Fig. 27 shows that the arc of contact

between the wheel and the work increases in magnitude with increases in (1) diameter of the work, (2) depth of cut. The greater the arc of contact, the greater the friction: the greater the friction, the greater the heat. Undue heating must be avoided at all costs. Consideration of the arc of contact enables the following simple conclusions to be drawn—

(*a*) The speed of the work must bear relation to its diameter. As

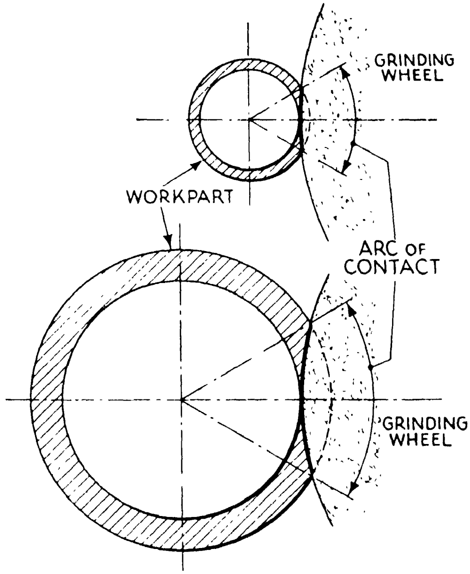


FIG. 27. THE ARC OF CONTACT

the diameter of a workpart is decreased the faster may be the work speed.

(*b*) The deeper the cut the greater the arc of contact. Hence work speed must be reduced when the depth of cut is increased.

(2) **Material.** It is impossible to give a useful table of work speeds suitable for thread grinding on different materials. As his experience widens, the operator naturally makes a mental classification of some materials he considers "easy to grind," and of others he considers "hard to grind." A beginner, accustomed to conventional machining practice, involving the use of ordinary cutting tools, may be pardoned for thinking that it is necessarily easier to thread-grind the free-cutting mild steels than the high-duty steels. Actually, when use is made of the most suitable work speed, grinding wheel, etc., it is often found that less difficulty arises in grinding high-speed steels than ordinary mild steels. No rules, then, can be given to relate work speeds to the materials of workparts. It is a matter best decided by trial and error.

It must be borne in mind that the work speed has a direct effect upon the cutting action of the grinding wheel; furthermore it

influences the rate of stock removal. "The slower the speed of the work, the deeper the cut that can be taken."

(3) Degree of Accuracy Required. In general it can be said that the higher the standard of accuracy required in the product, i.e. in regard to dimensions and surface-finish, the longer the time necessary to complete the grinding of any given job. By and large, therefore, the higher the standard of accuracy called for, the lower should be the work speed. However, if the work speed is *too* slow the result is burning of the workpart, unless the depth of cut is very small.

GRINDING A TRIAL THREAD. Having dressed the grinding wheel and set the machine to accommodate the given workpart, the beginner may be well advised to grind a specimen thread on a sample or test piece, before proceeding to thread-grind the actual workparts. The test piece may be a piece of scrap material of somewhat the same size as the workpart; alternatively, a workpart scrapped after a previous machining operation may be available.

GRINDING MAJOR DIAMETERS. In Fig. 15 and the relevant notes it is emphasized that the major diameter on a worm or on a flat-crested thread is ground by means of a flat-faced grinding wheel, i.e. one having cylindrical form. The face of the wheel may be dressed by using the diamond truing mechanism or, alternatively, by using a crushing roller. If the latter is used the formed grinding wheel can also "top" the major diameter while the thread groove is being ground. This is explained in Chapter III.

Where a diamond tool is employed to dress a flat face on the periphery of the wheel it is essential to exercise care in adjusting the speed and feed of the diamond traverse. A slow speed and a light cut produces a smooth face on the wheel, whereas a fast speed and a heavy cut leaves ridges and feed marks on the wheel. Ridges on the wheel are, of course, transferred to the ground surface of the workpart. This is detrimental in all except roughing-out operations.

When the major diameter is ground in a separate operation the operator must see that workparts are mounted so that the major diameter will be ground concentrically with the pitch diameter.

When major diameters are ground separately it is essential that a reasonable amount of surplus material, or "stock allowance," be provided to ensure that all "witness marks," left from the roughing-out of the blank, can be ground away. When the thread grinding of a workpart follows its heat treatment a sufficient stock allowance should be provided to allow for the removal of scale and minor shape distortions.

STOCK ALLOWANCE MORE FULLY CONSIDERED. A workpart to be thread ground from the solid blank should have enough surplus material on the major diameter to allow for eccentricity and out-of-roundness, as well as to enable the grinding wheel to clean up the surface completely—leaving it without witness marks from previous operations. The actual amount of this necessary stock allowance depends, of course, upon the condition of the blank and the method of holding it. An

excessive stock allowance throws more work on the grinding wheel; insufficient allowance leads to difficulty in obtaining a high standard of surface finish.

Stock allowances, as tabulated below, will be found satisfactory for the general run of work.

TABLE OF STOCK ALLOWANCES

(Applicable to blanks which run concentrically and are truly round)

T.P.I.	Diameters		
	Up to $1\frac{1}{2}$ in.	$1\frac{1}{2}$ to 3 in.	3 in. upwards
6 and Coarser	0·008 in.	0·010 in.	0·012 in.
7 to 12	0·006 in.	0·008 in.	0·010 in.
13 to 20	0·005 in.	0·007 in.	0·009 in.
22 to 30	0·004 in.	0·005 in.	0·007 in.
32 and Finer	0·003 in.	0·004 in.	0·006 in.

STOCK ALLOWANCE FOR PRE-CUT THREADS. On workparts with pre-cut threads a larger stock allowance must be left than on unthreaded blanks. The actual amount of the stock is fixed in relation to several factors, including (1) the size consistency of the previous threading operation, (2) the degree of accuracy with which the mounting of the work can be duplicated, (3) the method of aligning the roughed-out thread grooves with the thread ridges on the grinding wheel.

The stock allowance on the pitch diameter may advantageously be more than the allowances on the major and minor diameters. A general rule is to stipulate twice the allowance of stock on the pitch diameter that is allowed on the major and minor diameters.

Exceptions to the latter rule occur, for example, when dealing with steels which are case-hardened after the pre-cutting operation. Special care must be taken when matching up case-hardened pre-cut threads with the grinding wheel. Off-pitch grinding may result in one side of the thread being soft, due to the hard skin being ground away.

GRINDING ANNULAR GROOVES. Typical of many examples of work having "threads without lead," i.e. "annular grooves," are (1) thread milling-cutters, (2) circular, tangent, and flat-jaw type chasers, (3) crushing rollers, (4) rollers for screw-thread caliper gauges.

Annular grooves may readily be ground by using a multi-ribbed wheel and giving the work a rotary motion unaccompanied by any axial movement. The width of the grinding wheel should preferably be such that it contains a greater number of thread ridges than are required on the workpart. This eliminates the possibility of errors in pitch which otherwise result from moving the table or the work to enable indexing of adjacent series of grooves.

Occasion may arise when a wheel of sufficient face-width cannot be

used, or a multi-ribbed wheel cannot be used because the thread-grinding machine is designed to use a single-ribbed wheel only. In such cases accurate spacing of the grooves may be obtained by using special purpose mandrels, or by controlling the movement of the work-table by intermittent action of change gears. Another method is to move either the work or the table manually and to determine the traverse by using an indicating gauge and slip gauges.

MANDRELS. Screwed mandrels, having a pitch of thread suitable for the spacing of the grooves, can be used in conjunction with graduated collars. The work is ground with one or more grooves and then the collar is rotated to give an axial displacement of the work along the mandrel equal to one pitch of the grooves. The work is then locked in its new position and another groove is ground. By repeating the process the desired number of grooves can be ground on the workpart.

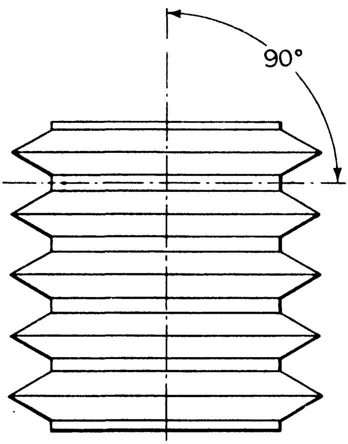


FIG. 28. TYPICAL ANNULAR GROOVES

Another type of mandrel is slotted to receive a number of slip gauges, or spacers, which are equal in thickness to the pitch of the grooves to be ground. When the first groove has been ground, a slip gauge or spacer is added and another groove is ground adjacent to the first. Additional spacers are used to grind the number of grooves required.

JONES & LAMSON HOBBING BOX. A special-purpose hobbing box can be used on the Jones & Lamson thread-grinding machines. This item incorporates a geared Geneva plate mechanism for the accurate spacing of annular grooves. In action, the work spindle rotates constantly and after one groove has been ground the grinding wheel is withdrawn from the work and the work-table moves axially a distance equal to the pitch of the grooves. The table traverse mechanism is then disengaged and the grinding wheel is fed into the work to grind the second groove. Repetition of these movements results in a series of annular grooves, the pitch of which is controlled by change gears—the entire operation being automatic.

GRINDING TAPERED THREADS. Provision is usually made on modern thread-grinding machines for grinding tapered threads to a high standard of accuracy. Satisfactory methods of obtaining the necessary angular displacement of the axis of the workpart can, generally speaking, be classified as (1) The Master Plate Method, (2) the Sine Bar Method, (3) Special Taper Attachment.

The Master Plate Method. The master plate, or "former bar," is a

precision-ground plate having the same angle as that required on the workpart. The function of the "former" is to provide for the gradual and constant increase in the ground diameter of the work as it rotates and traverses axially. For each taper an individual "former" must be used. See Fig. 29.

The Sine Bar Method. In this ingenious but simple application of the sine bar principle the necessary angle of taper is obtained by the use

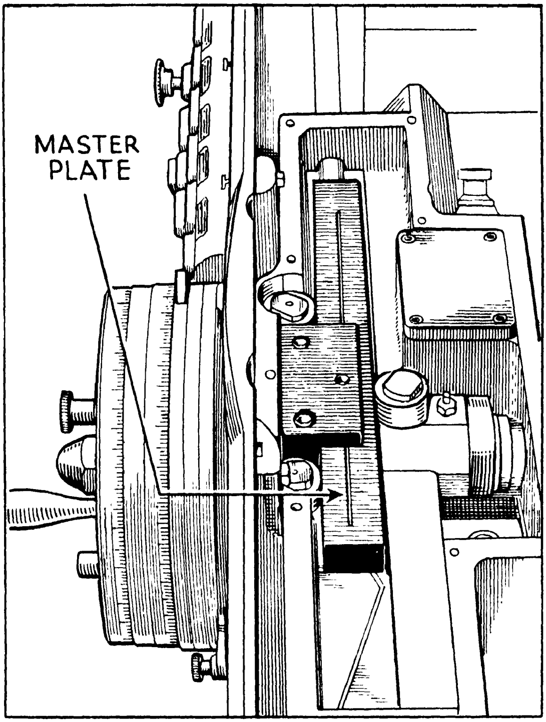


FIG. 29. MASTER PLATE USED ON EX-CELL-O MACHINES

of a sine bar,* attached to the workslide and adjusted to any required angle by means of slip or block gauges, or alternatively by micrometer settings. Thus, in this method one bar or "former" is used and different angles obtained by using appropriate combinations of slip gauges.

Taper Attachment. In Fig. 30 is shown an "Ex-Cell-O" taper attachment by means of which correct taper threads up to 3 in. per foot included angle can be ground. The attachment consists of a linkage which engages an adjustable plate graduated in taper per foot for quick setting. To grind taper threads the graduated plate is set to

* For illustrated descriptions of sine bars, with notes on their uses, see *Engineering Inspection*, by A. C. Parkinson (Pitman).

the desired angle of taper and then locked in position. As the table traverses axially, the correct taper is ground on the workpart.

A Less Accurate Method. This entails setting the tailstock centre out of alignment with the headstock centre, as is done in taper turning

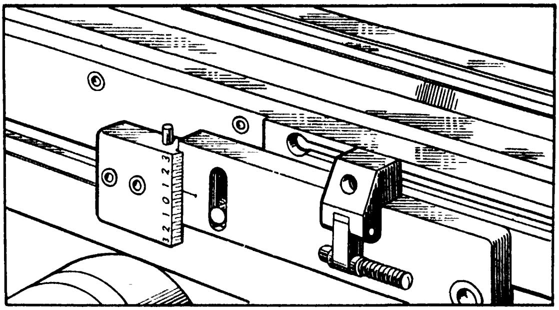


FIG. 30. TAPER GRINDING ATTACHMENT

on a lathe by adjusting the compound tailstock. Whilst this method may be suitable for grinding a small amount of taper (as often required on taps) and for correcting taper which may be discovered during the

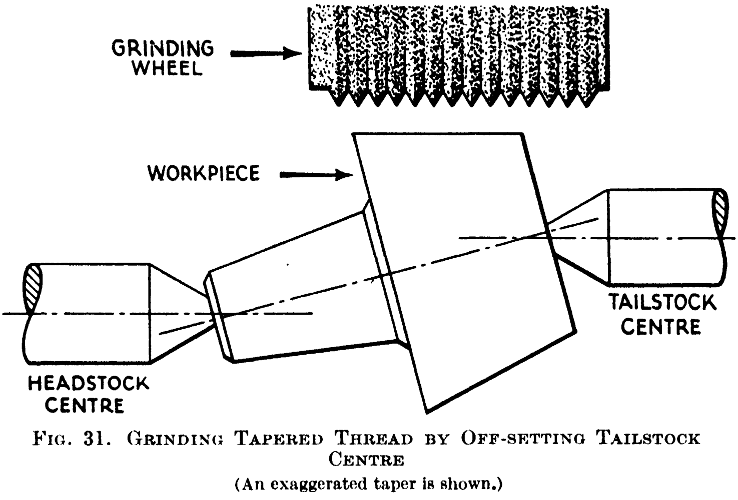


FIG. 31. GRINDING TAPERED THREAD BY OFF-SETTING TAILSTOCK CENTRE

(An exaggerated taper is shown.)

grinding of parallel threads, it has manifest disadvantages, included among which are—

(1) The thread form will be ground normal to the axes of the machine centres and not normal to the axis of the work. This results in a tilted thread.

(2) Inaccuracies in pitch will occur unless this is compensated for when calculating the change wheels.

(3) The machine centres will rapidly wear "out of round" and the work centres be damaged.

(4) Variations in the length of the workparts will cause variations in the rate of the taper.

Notes on Tapers. Screw threads for special purposes may be cut or ground on tapered blanks, and the taper may be expressed in various ways, e.g.—

(1) By stating the alteration in the diameter of a part per unit length, the latter being measured along the geometric axis. This is recommended by the B.S.I.

(2) By stating it as 1 in the length which gives unit change in the diameter. This is recommended by the Institution of Engineers, Australia.

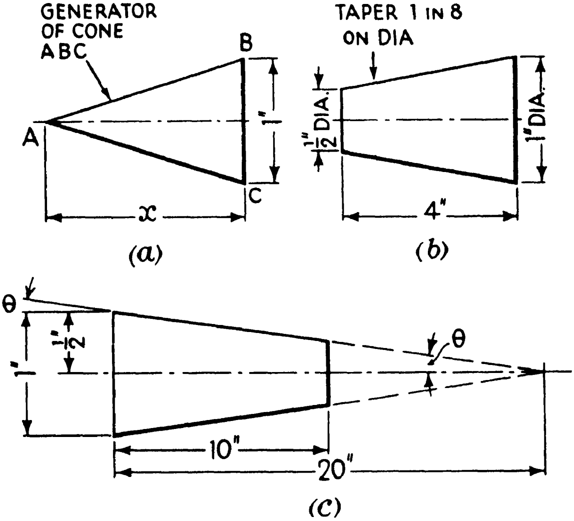


FIG. 32. METHODS OF INDICATING TAPER

(3) By stating the angle between two generators, or "sides," of the cone.

(4) By stating the angle between a generator, or "side," of the cone and its axis.

Referring to Fig. 32, at (*a*) *ABC* represents the front view of a cone. Its length is x units; its largest diameter (*BC*) is 1 unit. These units are purely arbitrary, i.e. they may be inches, centimetres, feet, etc. *The taper is* 1 *in* x. If x is 10 in., then *BC* is 1 in. If x is 20 in., then *BC* is 2 in., and so on.

Again, as the taper is 1 in x,

It must also be $\frac{1}{x}$ in 1.

At (*b*) is shown a tapered plug, shaped like a frustum of a cone. The total alteration in diameter is ½ in. per 4 in. of length. *Expressed as alteration in diameter per unit length* this is a taper of ⅛ in. in 1 in., or ⅛ in 1. *Expressed as* 1 *in the length which gives unit change of diameter* this is a taper of 1 in 8.

The angle, rather than other data, is given on some drawings. Thus, a tapering piece is shown at (*c*), where we are given (1) diameter of large end; (2) length of frustum, (3) length of cone. The angle can be calculated thus:

$$\tan \theta = \frac{0\cdot5}{20} = 0\cdot025$$

$$\therefore \theta = \tan^1 0\cdot025$$

$$= 1^\circ\ 26'.$$

Conversion Rules

Given	Required	Method
Taper per inch	Taper per foot	Multiply taper per inch by 12.
Taper per foot	Taper per inch	Divide taper per foot by 12.
Two end diameters of frustum and length of axis	Taper per foot	Subtract small diameter from large. Divide by length of axis. Multiply product by 12.
Large diameter and length of axis in inches, and taper per foot	Diameter of small end in inches	Divide 12 into taper per foot. Multiply by length of axis. Subtract result from large diameter.
Taper per foot	Amount of taper in a certain length of the axis, in inches.	Divide taper per foot by 12. Multiply answer by given length of axis.

Standard Thread Tapers. Two widely-used taper threads are (1) the British Standard Pipe Thread, (2) The American National Pipe Thread (formerly known as the Briggs Thread).

Both have a taper of 1 in 16, measured on diameter. This is equivalent to an angle of $1^\circ\ 47'$ on one side of the axis (corresponding to θ in Fig. 32).

BUTT-END THREADING. The end of a thread should preferably come to an abrupt finish, leaving a full end section of thread. This is shown in Fig. 113. For this operation, involving the removal of the feather edge of the thread, a flat-faced wheel is used, having a face-width approximately equal to the pitch of the thread.

When end-threading worms and hobs of large size it is advisable to grind the butt-ends so that when finished they are diametrically opposite. This tends to preserve balance.

GRINDING INTERRUPTED THREADS. It is not uncommon to use taps, chasers, and thread-milling cutters having interrupted threads. The chief object of removing alternate teeth is to obtain a more free cutting action. If alternate teeth are removed the chips more readily clear themselves from the tool, thus reducing the possibility of scouring and jamming in the threads. There is also a reduction in the necessary cutting torque and in the torsional stress. The ready clearance of chips and swarf from threading tools is of particular advantage when cutting materials like copper, bronze, aluminium, etc.

The alternate teeth are ground away with a flat-crested grinding wheel having very little more face-width than the root thickness of the thread. It is a further advantage to relieve,* or "back off," the root space. Some thread-grinding machines are equipped with a cam-acting

* A fully detailed discussion of the pros and cons of the relieving operation on taps will be found in *Cutting Tools for Metal Machining*, by Professors Kurrein and Lea (Chas. Griffin).

mechanism to enable indexing for grinding away alternate teeth after the thread has been ground in the usual manner. If such special-purpose equipment is not available, the indexing is done manually, by using a graduated headstock. When dealing with large quantities of tools requiring interrupted threads it is usual first to grind the complete

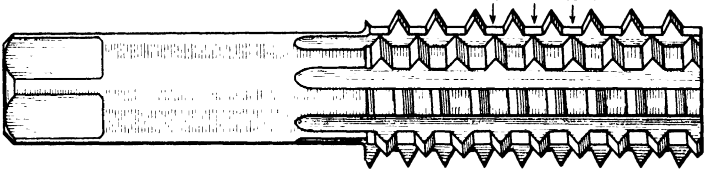


FIG. 33. A TAP WITH INTERRUPTED THREAD

threads in the usual manner and then "interrupt" them in a second operation, using a wide-faced wheel formed for a two-start thread of the same pitch and form as the thread being ground. When dressing this wheel one start of the two-start thread is omitted.

ITEMS OF EQUIPMENT

MANDRELS. Hollow workparts are held on mandrels mounted

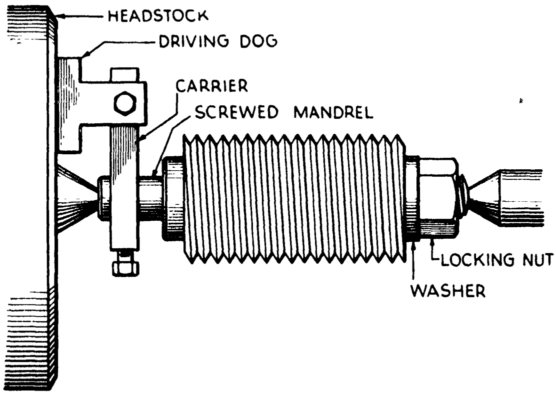


FIG. 34. WORK HELD ON SCREWED MANDREL

between the machine centres, unless the diameter of the bore is large enough to allow the use of a chuck.

The mandrel may be of the plain solid steel type, having a slight taper on the diameter and so made that it is a tight fit in the bore of the workpart. Should there be much variation in the bore dimensions of a batch of workparts it would be necessary to carry a stock of these mandrels differing slightly in diameter.

Another type of mandrel has one end threaded and has register diameters, or other means of locating the workparts—which are

clamped into position with a locking nut and washer. A typical set-up involving the use of a screwed mandrel is shown in Fig. 34.

A third type of mandrel is the "expanding mandrel" which is made in various forms, in all types the purpose being to provide a means of adapting a single mandrel to suit a range of bore diameters.

Accuracy in the concentricity of the various "diameters" on a thread ground workpart depends in no small measure on the accuracy of the mandrel. Evidently its "centres" must be well-made initially, and well-kept subsequently, if the mandrel is to run true.

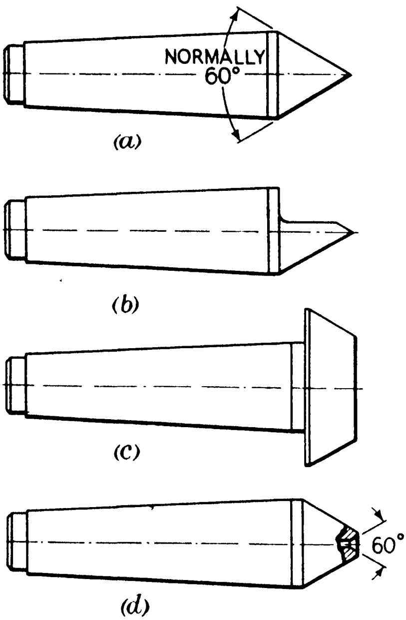


FIG. 35. TYPICAL MACHINE CENTRES
(*a*) Full centre, (*b*) Half centre, (*c*) Centre for work with large bore, (*d*) Female centre.

THE MACHINE CENTRES. It seems superfluous, indeed almost platitudinous, to remark that the successful operation of a thread-grinding machine requires that the centres of both headstock and tail-stock be kept in first-class condition—the same applying to the machined centres of the workparts and mandrels. Unless the machine centres are periodically trued they inevitably wear "out of round" and cause defects such as ovality and poor surface finish in the workparts.

The centres, both of the machine and the workparts, must be (1) in correct alignment, (2) of the same angle, (3) perfectly round, (4) absolutely clean, (5) well lubricated. Further, the machine centres must be a perfect fit in their respective sockets.

It is now becoming common to use machine centres which are reinforced with a tungsten carbide tip—but even these require occasional re-grinding.

If machine centres become so worn as to need replacement it is advisable to use good quality alloy steel in preference to ordinary high carbon steel. The authors have used high-speed steel successfully.

Cone Centre Grinder. The Jones-Shipman Cone Centre Grinder, arranged with a vertical spindle on the lines of a light drill press, grips abrasive grinding centre-wheels of the forms shown in Fig. 37. Their descriptions are given on p. 43.

Jones-Shipman Hints to Operators: The angle of the centre holes must be the same as that of the machine centres, or the work will be ground out of round.

Centre holes in repetition work should be uniform in depth, otherwise much time is wasted in re-setting stops when grinding to shoulders.

Centre Lapping Machine. In cases where ground workparts are required to conform to high standards of accuracy it is nowadays common practice to lap

the female centres—the same applying to mandrels used in high-precision turning and grinding. For this purpose a centre lapping machine is employed to correct errors in alignment, angle and roundness. Standard abrasive stones and pencil wheels are used on these machines, a diamond dresser being used to true the wheels to the desired angle, and to keep them in good condition by frequent re-truing.

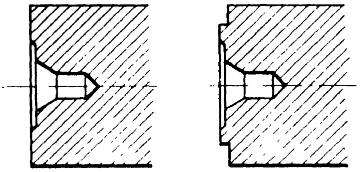


FIG. 36. CENTRE PROTECTION RECESSES

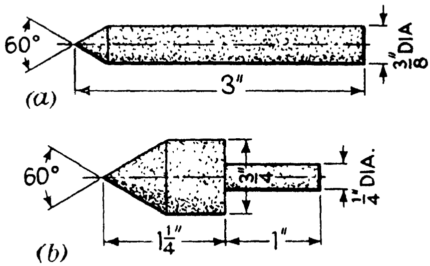


FIG. 37. ABRASIVE "CONES" USED IN CENTRE GRINDER

Abrasive Cones supplied by	Firm's Description Type (*a*)	Firm's Description Type (*b*)
Carborundum Co. Ltd.	Aloxite 100–H–33	Aloxite A 120–P–180
Norton Grinding Wheel Co. Ltd.	Bauxilite Vitrified 100–P	White Bauxilite Vitrified 120–J–G3
Universal Grinding Wheel Co. Ltd.	Alundum 120–P	Alundum 38120–IBE

WORK STEADIES. When a long slender workpart is held between centres there is bound to be flexure, due to the weight of the workpart and to the pressure between it and the grinding wheel. Unless workparts are supported by some form of *steady,* or *steady rest,* they cannot be ground accurately. Usually they are oversize in the middle.

Three-point Steadies. These have three jaws or rollers, a means of adjusting the tension of each being provided. The three jaws envelop the work more completely than those of two-point steadies, and thus comprise a sound support. They should bear upon some part of the work that does not require thread grinding.

Two-point Steadies. These do not envelop the work and therefore are used in closer proximity to the grinding wheel.

One steady or more may be used, depending on the length and weight of the work in relation to its diameter. When adjusting a steady, it is necessary to avoid distorting the work by undue tension, also to ensure that the jaws ride on a true-running part of the work.

Follow-rests. These are similar in construction to two-point steadies, but are attached to the wheelhead and not mounted on the bed of the machine as is the case with steady-rests. Thus the follow-rest remains

stationary and provides direct support against the pressure of the grinding wheel. Ample lubrication should be provided to avoid the ground surface being marked or scored by the jaws of the follow-rest. Follow-rests are successfully used for grinding long slender workparts. Hard wood is often used for steady-rest shoes, though sometimes cemented carbide is used.

CHUCKS. When the physical dimensions of the workpart are such that the work cannot be held between the centres of the machine, use is made of a chuck or a faceplate. Four types of chucks are in everyday use. They are—

(1) Drill chuck.
(2) Collet chuck.
(3) Three-jaw universal chuck.
(4) Four-jaw independent chuck.

Drill Chuck. This type of chuck is widely used for grinding small workparts, such as B.A. taps and the smaller sizes of Whitworth and B.S.F. taps. The chuck has three jaws and is self-centring.

Collet Chuck. This chuck is in the form of a split cylinder having a bore suitable for the diameter of the workpart to be ground. The chuck has a male taper on the projecting end which is pulled into a female taper, thus closing the jaws of the collet on to the workpart.

The opening and closing of the collet is effected by means of a lever or a handwheel and is extremely fast in operation. For the latter reason the collet chuck is widely used for grinding bulk quantities of workparts.

Three-jaw Universal Chuck. This is sometimes referred to as a "scroll chuck" and is so made that by turning a wrench in any one of the three pinion sockets all three jaws may be closed or opened in unison.

The three-jaw chuck is used for holding partly-machined workparts, particularly where the lengths of the latter are great in proportion to their diameters. In this case it is customary to pass one end of the workpart through the chuck and into the bore of the headstock spindle. The other end of the workpart is supported by the tailstock centre or by steady rests.

Four-jaw Independent Chuck. This chuck, as the name implies, has four jaws which can be independently moved, either towards or from the centre. This type of chuck is used for mounting work of irregular shape where considerable adjustment is necessary to ensure that it will rotate concentrically.

FACEPLATES. Faceplates similar in construction to those used on other types of machine tools are sometimes used for grinding workparts which cannot readily be held in a chuck. In addition, an angle plate may be attached to the faceplate to facilitate mounting of the workpart.

Special Equipment in addition to the foregoing items includes the following—

(*a*) Special purpose work-holding fixtures.
(*b*) Diaphragm chucks.
(*c*) Magnetic chucks and face-plates.
(*d*) Pneumatic chucks and jigs.
(*e*) Automatic-action work loading and ejecting devices.
(*f*) Pre-cut thread matching devices.

CHAPTER V

GRINDING WHEELS

THIS chapter deals with the construction and cutting action of grinding wheels and the selection of the correct wheel for a given job. The notes on the manufacture of grinding wheels are brief and make no pretence of covering every aspect of this complex subject. They are framed as a descriptive outline of the process, intended to provide a useful background to the reading of later sections in the chapter.

Not inaptly referred to as "the business end of the grinding machine," the grinding wheel should be visualized as a rotating cutter with numerous cutting edges. Obviously it is essential that it functions with maximum efficiency if satisfactory results are to be obtained. The A.S.A. definition is as follows: "An abrasive wheel is a power-driven wheel consisting of abrasive particles held together by artificial, or natural, mineral, metal, or organic bonds."

MANUFACTURE. A grinding wheel is made by mixing grains of abrasive with a bonding material in such a way that when set and ready for use the wheel material contains a number of voids. Various kinds of abrasive particles are used, their sizes varying considerably for different purposes. Similarly there are various bonding materials, or *bonds*, and the quantity of bond in relation to the number of abrasive particles is decided upon according to the purpose for which the wheel is required. Following the mixing operation the substance is placed in moulds suitable for the shape and size of the wheels required. The filled moulds are placed in an hydraulic press and, under accurately controlled pressure, the wheels are confirmed in their required shapes.

In the "green shape" the wheels are then dried and transferred to specially prepared ovens for the baking operation. The heat causes the bonding agent to "run" and so completely cover every grain of abrasive. The bonding agent is then allowed to solidify.

Speed testing is an important subsequent operation during which the wheel is rotated at an abnormally high speed to ensure that there is an ample margin of safety when it is run at maximum cutting speed. Wheel breakages daily become more rare; indeed, in every instance of wheel breakage recently experienced by the authors the cause has been traced to non-compliance with the wheel manufacturer's recommendations.

Information is given later in this chapter on *bonds*, but at this stage it can be stated that most grinding wheels are made by the *vitrified process* which, in brief, consists of mixing the abrasive with the correct mixture of clays of predetermined characteristics, moulding to approximate size in hydraulic presses, or by other suitable means, and burning in kilns to a high temperature *to vitrify the bond.* A bond produced in this way is really a high-temperature glass or porcelain. After vitrifying, the wheels are generally dressed all over and, after speeding and

inspection, they are ready for use. Wheels made in this way have a very strong bond and are obtainable in a range of grits and grades.

ABRASIVES. The abrasives most commonly used in modern grinding-wheel manufacture are made synthetically. Their scientific names and chemical symbols are as follows—

(1) Silicon carbide (SiC).
(2) Aluminium oxide (Al_2O_3).

Both these materials have special features and advantages. Both are produced in varying degrees of friability or brittleness.

Silicon carbide is made by heating a mixture of sand, coke, sawdust, and salt in a resistance-type electric furnace which combines the silicon of the sand with the carbon of the coke to form silicon carbide. The crude material from the furnace is crushed, graded by screening to the required grit size, washed with acids and alkalis to remove impurities, then magnetically treated to remove iron. It is then ready for processing into grinding wheels.

Aluminium oxide is made by heating bauxite in an arc-type electric furnace which drives off the chemically combined water and forms the crystalline aluminium oxide. The crude material from the furnace is crushed and treated in a manner similar to that used in treating the crude material when obtaining silicon carbide. Aluminium oxide is not so hard as silicon carbide, but is tougher.

Silicon carbide is suitable for grinding brittle and hard materials of low and medium tensile strengths. The softer and tougher aluminium oxide is suitable for grinding soft and tough materials of higher tensile strengths.

Grain Size or Grit. Grains of abrasive vary considerably in size. Great care is expended in separating the grains into an extensive range of sizes. They are classified into groups as *very coarse*, *coarse*, *medium*, *fine*, and *very fine*. Each group is sub-divided into standard numbers corresponding to the number of meshes per inch in the screen or sieve through which they will pass, e.g. a 46-grit will pass through a sieve having 46 meshes to the linear inch.

Grit or grain numbers used by the Carborundum Company Ltd. are as follows—

Very Coarse	*Coarse*	*Medium*	*Fine*	*Very Fine*
6	12	30	70	150
8	14	36	80	180
10	16	40 or 46	90	220
	20	50 or 54	100	240
	24	60	120	1 F
				2 F
				3 F

Some of the very fine grits known as *Flour* sizes, used mainly for lapping, are designated by numbers such as 280, 320, 400, 500, 600.

Combinations of various grit sizes are also used in making grinding wheels, depending upon particular requirements of the grinding operation. The very fine grits are graded by methods other than screening, e.g. by precipitation and flotation.

In thread grinding the abrasive wheel has to be dressed to a sharp Vee edge or a small radius, to maintain which it is clearly necessary to employ a wheel having fine abrasive grains. To take an example: it would obviously not be practicable to true a wheel containing No. 46 grit abrasive (average grit diameter 0·018 in.) down to an edge measuring

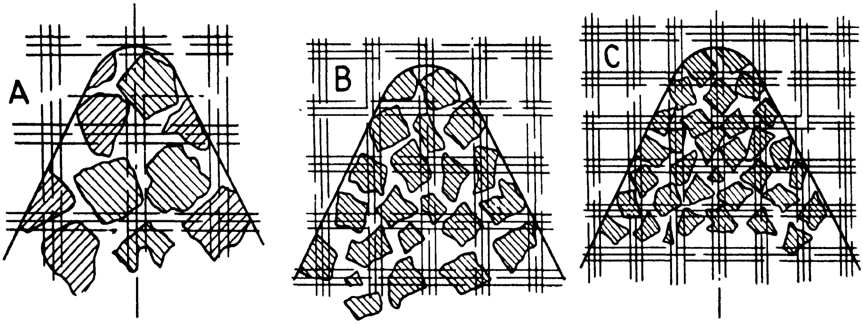


FIG. 38. WHEEL STRUCTURE

Showing how grain size controls thread forms that can be produced on wheels and how free-cutting properties are controlled by structure.

(*A*) Structure of 120 graded wheel showing comparative size of grains and mesh with radius for 26 t.p.i. Grains are too big. Very free cutting, but form will be bad.

(*B*) Wheel formed of grains of 180 mesh compared with radius for 26 t.p.i. Free cutting. Better form than (*A*).

(*C*) Structure of wheel formed of grains from 220 mesh and profiled to 26 t.p.i. Grains allow correct radius to be obtained and the wheel will cut properly. Free cutting. Good form maintained.

(*Courtesy of Coventry Gauge and Tool Co. Ltd.*)

0·005 in., such as would be necessary to grind a very common thread. In practical thread grinding it is seldom that wheels coarser than No. 100 grit can be used. The Norton Company give No. 120 to No. 150 as average. For other precision grinding operations (other than for ultra-fine finish) the average grit size lies between No. 46 and No. 80. Here, then, is the principal difference between thread-grinding wheels and wheels used for other cylindrical grinding operations.

The Norton Company stress that the pitch of the thread to be ground very largely controls the grit size that can be used successfully, although this is influenced by the skill of the operator and the condition of the diamonds. "A skilful operator with good diamonds can use a considerably coarser wheel for a thread of given pitch than is possible with less skill or with worn diamonds."

Another factor which may influence choice of grit is the quality of finish required. If on threads of relatively coarse pitch a very high finish is required it may be advisable to use a finer wheel than is required to hold the proper root radius.

The Carborundum Company has kindly supplied the following

table "to give some guidance to the approximate grit sizes for various pitches of thread"—

Grit	*T.P.I.*
100–120	10
150	20
180–220	30
1F (240–280)	40
2F–3F (400–500)	60–80

The Landis Tool Company's recommendations are as follow—

T.P.I.	40	32	28	24	20	18	16	13	11
Grain Size	400	320	320	320	220	220	180	150	150

BONDS. Bonds are cements used for holding the grains of abrasive in place. For wheels employed in *general grinding* practice the bonds are of five main types, namely—

(1) vitrified.
(2) silicate.
(3) shellac.
(4) synthetic resin, or resinoid.
(5) rubber.

The vitrified bond is the most widely used in conjunction with both silicon abrasives and aluminium oxide abrasives.

For *thread grinding* the abrasive wheels employed can be divided into two general classes, viz. (1) vitrified, (2) resinoid. Vitrified bonds are non-organic; resinoid bonds are organic. Organic bonds include bakelite, rubber, shellac, etc. We have previously referred to the glass-like consistency of vitrified bonds, yet this bond is rather more "open" structurally than the silicate bond. Porosity favours the functioning of the coolant. A rubber bond is "springy" and less brittle than other bonds. It is capable of high resistance to fracture as a result of side thrusts or stresses acting parallel to the spindle. A common use for thin wheels is for parting off, as well as for rapid stock removal.

GRADE OR RELATIVE HARDNESS. This is the tenacity or degree of strength with which the particles of abrasive are held in the wheel against grinding pressure. Force is necessary to detach the particles from the wheel and one of the chief factors determining this force is the quantity of bonding material in relation to the quantity of abrasive particles employed during manufacture. Grade is defined by the Carborundum Company as *the resistance which the composite effect of grain and bond offers to the grinding forces which tend to break down the wheel structure.* The various grades are obtained by varying (1) the amount and composition of the bond, (2) the shape and distribution of what are called *pore spaces* or *voids.*

Grade is indicated by different firms in different ways. Thus the Norton Company's grading is as follows—

Very Soft	*Soft*	*Medium*	*Hard*	*Very Hard*
E	H	L	P	T
F	I	M	Q	U
G	J	N	R	W
	K	O	S	Z

NOTES

(1) If the abrasive grains are easily torn out from a wheel it is called "soft," or is said to be of "soft grade." Alternatively, if the grains can only be dislodged with great difficulty the wheel is described as "hard," or of "hard grade."

(2) The most economical wheel is, of course, one that is hard enough to stand up the longest and still retain good cutting quality. *In the case of resinoid wheels*, which are usually employed on high production work where the grains are working close to their capacity, the grades are much harder for thread grinding than for other precision-grinding processes. Common grades for Norton resinoid wheels are *R* to *U*.

As *vitrified wheels* are used under conditions where the grains are not working so close to their capacity, the grades are more nearly like those used for other precision-grinding processes. Common grades for Norton vitrified wheels range from *J* to *M*.

It should be noted that with both resinoid and vitrified wheels harder grades are required for grinding taps and splined screws than would be required for grinding plain screws of the same size and pitch.

The Carborundum Company's grading is as follows—

	Vitrified or Silicate	*Shellac*	*"Redmanol"*	*Rubber*
Very Hard	D, E	—	—	A
Hard	F, G, H	1, 2	3, 4, 5	B, C, D
Medium	I, J, K, L, M	3, 4, 5	6, 7, 8, 9, 10	E, F
Soft	N, O, P, R, S, T	6, 7, 8, 9	11, 12, 13, 14, 15, 16	—
Very Soft	U, V, W	10	17	—

NOTE

"Redmanol" wheels are produced by the Carborundum Company. "Redmanol" is a phenolic resin, a synthetic organic compound. Wheels bonded with this material are cool cutting and remove stock rapidly. As cut-off wheels, for instance, it is claimed by the makers that they can be operated at speeds as high as 16,000 s.f.p.m.

PORES. These are the spaces, voids, or air-pockets existing between the abrasive particles and the bond. The relative size and spacing of the pores determines the *structure* of the wheel. One purpose of the pores is to provide chip clearance for the shavings of metal cut away from the workpiece by the abrasive particles. If the structure of the wheel is "open" there is more possibility of rapid stock removal

because room exists for the chips or shavings, thus obviating "clogging." The Norton Company grade their wheel structures as follows—

	Structure Numbers
Close or Dense Spacing	0, 1, 2, 3
Medium Spacing	4, 5, 6
Wide or Open Spacing . . .	7, 8, 9, 10, 11, 12

WHEEL MARKINGS. The symbols used as *Norton wheel markings* are arranged in the following order: grit number, grade letter, structure number. For example, 60–Q.7 describes a wheel of 60 grit size, Q grade, 7 structure number. If a letter is used after the structure number it indicates the kind of bond used; if a number precedes the grit number it indicates the kind of abrasive particle employed.

Thread grinding of ferrous metals calls for Alundum or 38 Alundum abrasive. A structure with widely spaced pores seems to be the best. Usually the only characteristics which a user needs to change are the grain size and grade. The usual range of grain sizes for this class of work is—

Coarsest: 90, 100, 120, 150, 180, 220 (finest).

The usual range of grades for vitrified wheels is the following—
Softest: J, K, L, M, N (hardest).

For resinoid wheels—
Softest: P, Q, R, S, T, U (hardest).

Norton wheel markings indicate the specifications for five wheel characteristics which can be varied to develop the best wheel for a given set of conditions. The following table graphically explains the system as applied to two different practical thread-grinding specifications, namely, 180–U9T and 38180–M10BE.

Type of Abrasive	Grain Size	Grade or Hardness	Structure	Kind of Bond
Blank (Regular Alundum)	180 (fine)	U (hard)	9 (wide)	T (Resinoid)
38 (38 Alundum)	180 (fine)	M (med.)	10 (wide)	BE (Vitrified)

CUTTING ACTION. The cutting action of a grinding wheel may best be described by likening it to a disc-type cutter. Every individual grain of abrasive on the periphery of the wheel represents one tooth of a cutter; thus we may visualize a coarse-grained wheel as a cutter with few teeth.

It is, of course, generally accepted that when using a milling cutter with few teeth it is practicable to take a deep cut and so remove a lot of material from the workpiece. This is partly due to the fact that there is sufficient clearance or spacing between adjacent teeth to allow for the escape of the swarf and work-chips during the cutting operation.

The peripheral speed of the cutter must, however, be slow enough to allow for a sufficient time-lag, or tooth contact interval, for the chips

to clear themselves from the cutter; otherwise they would choke up the cutter and thereby retard its cutting efficiency.

The faster the cutter speed the smaller becomes the amount of stock that can be removed for each contact between a tooth and the workpiece. It is not possible when using a cutter with many teeth to take such a deep cut as is possible when using a cutter with very few teeth. This is largely because of insufficient "chip clearance." The latter fact holds good regardless of the speed of the cutter. Therefore, it follows that a greater bulk of material can be removed for each contact-per-tooth when the cutter speed is comparatively slow.

As a general rule, it can be stated that the higher the cutter speed, and the shallower the depth of cut, the smoother is the surface finish. Therefore, for roughing-out operations a slow-speed cutter with few teeth, and a heavy depth of cut, may advantageously be used. Conversely, for finishing operations, where a smooth surface and consistent size is essential, it is advisable to use a cutter with many teeth, operating at a high speed and taking shallow cuts.

Assume that in one instance we use a cutter with forty teeth and that in a second instance a cutter with eighty teeth is used. Then, by increasing the speed of the forty-toothed cutter we could, in effect, obtain the cutting action of a sixty-toothed cutter. In addition, if we reduce the speed of the eighty-toothed cutter we could again obtain the effect of using a cutter with sixty teeth.

Appreciation of the foregoing is essential to a full understanding of the general principle underlying the provision of devices to enable the operator to vary the speed of the grinding wheel. The *wheel speed adjustment* enables him to obtain the cutting action of either a "harder" or a "softer wheel," with its accompanying influence on the work speed, rate of stock removal, and quality of surface finish.

Bearing in mind the analogy between a disc-type cutter and a grinding wheel, the following conclusions can be stated as general rules.

(1) *Increasing the peripheral speed of a grinding wheel has the same effect as is obtained when using a closer grained, i.e. "harder," wheel. A wheel speed that is too fast results in the cutting action being "too-hard" and causes the workpiece to become burned.*

(2) *Decreasing the wheel speed results in a cutting action such as is normally associated with the use of a "softer" wheel. A wheel speed that is too slow results in the cutting action being "too soft" and the wheel tends to rub rather than to cut. This causes premature breaking away of the thread form on the grinding wheel.*

NOTE

Reference to "wheel speed" should be accepted as applying to the peripheral speed of the wheel in surface feet per minute.

Example

A wheel of 15 in. diameter, rotating at 2000 revolutions per minute has an equivalent peripheral speed of 7850 s.f.p.m. A wheel of 10 in. diameter, travelling at the same number of revolutions per minute, i.e. 2000, has a peripheral speed of 5240 s.f.p.m.; a difference of 2610 s.f.p.m.

Wheel Speed, in feet per minute, is calculated thus—

Wheel Speed (s.f.p.m.) = Dia. of Wheel (in inches) × r.p.m. × 0·2618

(s.f.p.m. = surface feet per minute; r.p.m. = revolutions per minute; $0{\cdot}2618 = \pi/12$)

Table No. 1, page 184, gives the equivalent s.f.p.m. and r.p.m. values for wheel diameter increments which have proved most useful in practice.

Table No. 2 refers to internal grinding.

Work Speed, in feet per minute, is calculated thus—

Work Speed (s.f.p.m.) = Dia. of Work (in inches) × r.p.m. × 0·2618

Table No. 3, page 186, refers to work speeds.

The change to a harder or a softer cutting action by altering the speed of the grinding wheel is relative to the number of times that each grain of abrasive makes contact with the workpiece surface in any given time. This is readily visualized if it is imagined that the workpiece is stationary. In fact, of course, the work is rotating and this gives us another variable factor to influence the cutting action.

Without altering the wheel speed, we may bring any given part of the work more often into contact with the grinding wheel, in any specified time, by increasing the speed at which the work rotates. This would have the effect of using a softer-acting wheel—due to the fact that the speed of the wheel has virtually been decreased.

Leaving the wheel speed unchanged, and decreasing the speed of the work, makes the grinding wheel act "harder." This is because each individual grain of abrasive, or "tooth," comes into contact more often for each revolution of the work.

SUMMARIZED CONCLUSIONS

A *Harder* cutting action is obtained under the following conditions—

(1) Work speed unchanged—Wheel speed increased.
(2) Work speed decreased—Wheel speed unchanged.
(3) Work speed decreased—Wheel speed increased.

A *Softer* cutting action is obtained under the following conditions—

(1) Work speed unchanged—Wheel speed decreased.
(2) Work speed increased—Wheel speed unchanged.
(3) Work speed increased—Wheel speed decreased.

RANGE OF WHEEL SPEEDS FOR THREAD GRINDING. Machines designed for using *single-rib wheels only* have a speed range of 5000 to 12,000 s.f.p.m. For example, the Ex-Cell-O Model 33 thread-grinding machine has two standard speeds: 7000 s.f.p.m., and 9000 s.f.p.m. In some cases a lower speed is used for roughing-out operations. The design of modern machines is such that it is permissible in many cases to run certain vitrified wheels of approved grade at 12,000 s.f.p.m. even though this speed is normally considered far in excess of the maximum "vitrified speed." Such wheels must naturally be made and dressed to close limits for balance and general accuracy. Usual speeds for single-rib vitrified wheels lie between 6000 and 9000 s.f.p.m. and for single-rib resinoid wheels between 7000 and 10,000 s.f.p.m.

It must be pointed out, however, that the higher speeds do not necessarily give the best results in all cases.

Machines designed for using *multi-rib wheels only* have a speed range of 3000 to 7000 s.f.p.m. Due to the greater area of contact when using multi-rib wheels it follows that more heat and friction is generated than is the case when single-rib wheels are used. Thus it becomes necessary to have a lower speed range for multi-rib wheels.

WHEEL SELECTION. It is often possible to choose a wheel specification that has previously been satisfactory for a similar class of work to be ground. Occasion does arise, however, when the type of thread and material has not been experienced. In such an event the reader will find it useful to refer to the list of *Recommended Grinding Wheels for Thread Grinding* at the foot of this page.

The choice of the correct wheel will depend, of course, upon many factors pertaining to a given job. The following are among the points which should be given due consideration: pitch and form of thread; accuracy desired; size and shape of workpart; the material used; method of holding work; speed of the grinding wheel; work speed; rigidity of machine; quantity of workparts to be ground; the time allowed for the grinding operation; whether the work has been pre-cut by roughing-out on a lathe or other machine; the method of dressing the grinding wheel; frequency of re-dressing; type of wheel (i.e. single or multi-rib); method of grinding, etc.

As so many unrelated factors have a bearing on the matter it is obvious that no possible table could yield information which would cater for every wheel problem encountered in thread grinding. It must therefore be emphasized that the following list of grinding-wheel specifications is intended to serve as a useful starting-off point. The reader, when about to tackle a new job, should first choose the appropriate wheel from the list and give it a fair trial. Results will indicate whether selection of a wheel with other characteristics is advisable.

RECOMMENDED GRINDING WHEELS FOR THREAD GRINDING

WHITWORTH AND U.S. (NATIONAL) THREADS

T.P.I.	NORTON		CARBORUNDUM	
	VITRIFIED	RESINOID	VITRIFIED	RESINOID
3 to 8	3880–J8–BE	100–S9–TH	A803–P–180	E803–K4Y
8 to 11	38100–M8–BE	100–W9–TH	A100–P–180	E1003–K4Y
12 to 16	38120–K8–BE	150–T9–TH	A1203–P–180	E1203–K4Y
16 to 20	38150–K8–BE	180–T9–TH	A1203–P–180	E1203–K4Y
20 to 26	38180–M10–BE	180–T9–TH	A150–L–180	E1503–K4Y
26 to 32	38220–M10–BE	220–T9–TH	A180–L–180	E1803–K4Y
32 to 36	38220–K9–BE	220–T9–TH	A220–L–180	E2203–K4Y
36 to 48	320–09T		A1F–L–180	E2203–K4Y
50 to 80	38500–L		A3F–L–180	E2203–K4Y

British Association Threads

B.A. No.	NORTON		CARBORUNDUM	
	Vitrified	Resinoid	Vitrified	Resinoid
0 to 3	38180–M10–BE	180–T9–TH	A180–L–180	E1803–K4Y
3 to 6	38220–K9–BE	220–T9–TH	A220–K–180	E2203–K4Y
6 to 8	38320–L8	320–O9–T	A1F–L–180	E2203–K4Y
8 to 10	38500–L		A3F–L–180	

Acme and Worm Threads

T.P.I.	NORTON		CARBORUNDUM	
	Vitrified	Resinoid	Vitrified	Resinoid
3 to 7	3880–K8–BE	100–S9–TH	A803–P–180	E803–K4Y
7 to 10	38100–M8–BE	100–W9–TH	A100–P–180	E1003–K4Y
10 to 12	38120–J7–BE	120–T9–TH	A1203–P–180	E1203–K4Y
12 to 18	38150–K8–BE	150–W9–TH	A1203–N–180	E1503–K4Y
18 to 26	38180–M10–BE	180–T9–TH	A180–L–180	E1803–K4Y
24 to 32	38220–K8	220–T9–TH	A220–K–180	E2203–K4Y

Internal Threads

T.P.I.	NORTON		CARBORUNDUM	
	Vitrified	Resinoid	Vitrified	Resinoid
10 to 16	38120–M9–BE	120–T9–TH	A1203–N–180	E1003–K4Y
16 to 20	38180–M10–BE	180–T9–TH	A150–N–180	E1503–K4Y
20 to 30	38220–K9–BE	220–T9–TH	A220/F–N–180	E1803–K4Y

Production rates are of great importance in the shops and therefore have an influence on the choice of a wheel that will give a high rate of stock removal consistent with tolerable quality. This aspect of the matter is given noticeably more consideration in shops where incentive methods of payment are in operation.

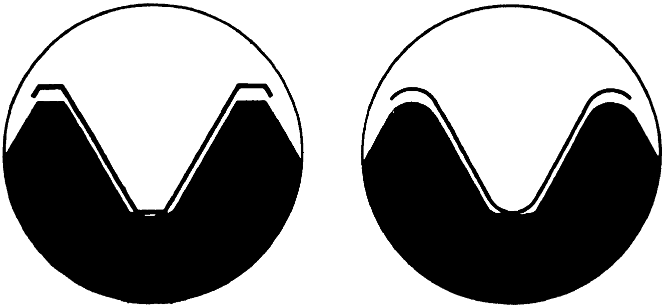
WHEEL-FORM ERRORS. The most prevalent wheel trouble is a collapsing of the thread profile on the peripheral rib, this being especially noticeable when grinding sharp corners or small radii on the smaller ranges of threads.

Two examples of wheel form breakdown are shown in Fig. 39.

The 20 t.p.i. U.S. National thread shown at (*a*) has the error of fillets forming on the thread root, caused by premature wear of the grinding wheel. A flattening of the root radius of a 20 t.p.i. Whitworth thread is shown at (*b*).

Wheel wear is readily caused by one or more of the following—

1. Grinding wheel too "coarse-grained."
2. Diamond tools blunted.
3. Truing feed too fast and too heavy.
4. Excessive depth of cut.
5. Wheel speed too slow.
6. Work speed too fast.
7. Inefficient cooling and lubrication.



(*a*) (*b*)

FIG. 39. EXAMPLES OF WHEEL-FORM BREAKDOWN

8. Wheel out of balance.
9. Insufficient rigidity of work mounting.
10. Diamonds too light for their duty.

NOTES ON THE FOREGOING LIST

(1) Here the grains of abrasive are too large to allow them to be dressed down small enough before they break away from the bond. Thus they are unable to assist in the maintenance of a sharp corner, or of a radius small enough in size for the form of thread being ground. As an example, it would be impossible to true a wheel containing No. 46 grit abrasive (average grit diameter 0·018 in.) down to an edge measuring 0·005 in. such as is required to grind a fine pitch U.S. National thread.

(2) If the diamond is blunt the wheel is *forced*, rather than *cut*, to form. The blunted edge of the diamond pushes away the grains instead of keenly cutting and truing the surface of the wheel.

(3) A diamond truing feed that is too fast in its traverse attempts more than a fair share of work, so tending to knock the grains of abrasive out of place. This is especially the case when the diamond has to take a deep truing cut. At any traverse speed it is better truing practice to take many light cuts rather than a heavy cut. Care taken to ensure that the diamond truing speed and feed is correct is repaid by increase in the life of the diamond.

(4) If the cut is excessively deep the wheel is called upon to do an unreasonable amount of work. The best way is to take lighter cuts and to pay special attention to wheel truing—particularly before the finishing cut.

(5) It has already been pointed out that when the wheel speed is too slow

we get the effect of a soft-acting coarse-grained wheel. This tends to rub chips from the workpiece instead of cutting keenly.

(6) If the work speed is excessive the effect is similar to that obtained by using a wheel that is too soft.

(7) Inefficient cooling and lubrication is not solely dependent upon the *quantity* of the grinding oil. Grade and quality are just as important—in some cases more so. Lack of efficient cooling and lubrication has a seizing and binding effect. The heat and friction combine to distort the wheel and to expand—inconsistently—the dimensions of the workpiece. Coolants are dealt with more fully in Chapter VII.

(8) A grinding wheel that does not run in true balance causes troubles other than a breakdown in thread form, e.g. hammering and chatter marks. An unbalanced wheel is likely to break while in use, with the possibility of injuring the operator and damaging the machine. Further references to wheel balancing will be found in Chapter VI.

(9) Work parts insecurely held vibrate during rotation and so hammer the wheel. Adverse effects, in addition to damage to the thread profile, include poor surface finish. Work supports and steadies should be used wherever practicable. Every care is essential when mounting the work.

(10) Diamonds which have been re-lapped suffer a loss of weight in the process. Their size is thus affected and a lesser amount protrudes from the seating. Such diamonds should be transferred to lighter duties. Diamond tools are more fully discussed in Chapter VI.

RESINOID OR VITRIFIED? In everyday thread-grinding practice it can be stated as a fairly general rule that an organic bond wheel is used for mass-production work, where parts are finished with fewest possible cuts at high speed. A vitrified wheel is used for the "Tool and Gauge Dept." type of work, requiring close tolerances on both form and lead.

Vitrified Wheels. The advantage of a vitrified bond wheel lies in its inherent rigidity—for a vitrified wheel is more rigid than a resinoid wheel of similar proportions. This is a property that enables the wheel to resist deflection under normal working conditions—a matter of some importance when grinding pre-cut* threads. Pitch errors may be present in a pre-cut thread and a flexible wheel would tend to follow and perpetuate such errors. Hence it is general practice to employ the more rigid vitrified wheels when grinding pre-cut threads.

Resinoid Wheels. As stated previously a resinoid wheel has an organic bond such as bakelite, shellac, rubber, etc. No doubt the range of organic bonds will be increased as time goes on.

The reader may wonder why a resinoid wheel is used in view of the fact that a vitrified wheel gives equal accuracy when grinding threads on an unthreaded blank, and superior accuracy when grinding pre-cut threads. The outstanding characteristic of a resinoid wheel is its ability to withstand abuse.

Operating speeds of resinoid bonded wheels are much higher than vitrified wheels. The maximum operating speed for resinoid wheels, as stipulated by the American Standards Association's Safety Code, is 9500 ft/min. For vitrified wheels the much lower speed of 6500 ft/min is the recommended maximum. Following rapid developments

* A pre-cut thread is a thread which has been roughed-out by milling, screw-cutting, casting, or any other method of threading.

by the grinding-wheel manufacturers it is most probable that the maximum speeds will soon be modified. However, in every case, the manufacturers' current recommendations should be strictly adhered to. It may be added that maximum speeds do not necessarily give the best results.

The higher operating speeds of resinoid wheels, coupled with their ability to withstand abnormal conditions, result in a faster rate of production by allowing heavy cuts to be taken at a relatively high work speed.

Generally speaking, it is more difficult to dress a resinoid wheel than a vitrified wheel. However, the resinoid wheel holds its form the

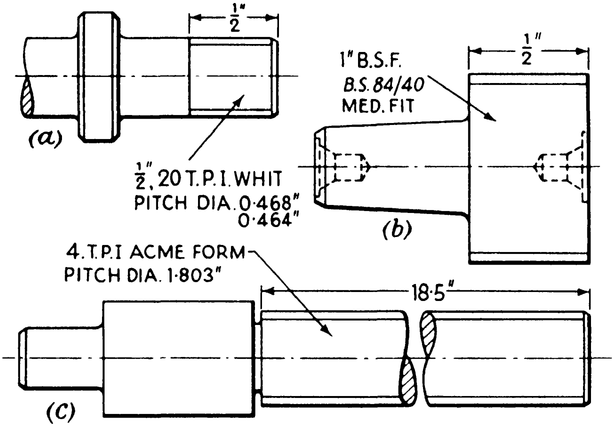


FIG. 40. WORKPARTS FOR THREAD GRINDING

longest and requires less attention after the initial truing. It follows that a resinoid wheel will grind the greater number of parts with the least attention.

TYPICAL JOBS. In Fig. 40, are shown three workparts together with such dimensions as concern the thread-grinding operation. These typical examples have been selected to emphasize the reasons for choosing and using their respective grinding wheels.

Fig. 40 (*a*). This is a stud requiring a ½ in. length of thread of Whitworth form. The tolerance on pitch diameter is 0·004 in. A pitch error of 0·0002 in. per 1 in. nominal length of thread is permissible. Material: stainless steel.

COMMENTS

The smaller the radii on a thread to be ground the smaller should be the grain size. In this example the thread has a pitch of $\frac{1}{20}$ in. and the corresponding radius is 0·0068 in. A grain size of about 0·008 in. average diameter is chosen, being the equivalent of No. 120 grit. If we had chosen a larger grain size, say No. 80, we should find it impracticable to dress these large grains to a radius of 0·0068 in. on the wheel form—certainly not to maintain it.

As the thread has a liberal tolerance, and is ground from the solid, a fast production time is desirable. For this type of job a 120-grain-size, resinoid bond

wheel, operating at about 9000 ft/min could be used. The work speed would be 4 ft/min. and the thread would be ground at one pass of the wheel. A floor-to-floor time of 1½ min was obtained when using a single-rib type of grinding wheel.

Fig. 40 (*b*). This is a screw-plug gauge. Attention must therefore be focused on accuracy of form and of dimensions. A vitrified wheel would be used.

COMMENTS

A wheel of 100 grit size is suitable and for the roughing cuts the wheel speed would be about 4800 s.f.p.m. With a work speed of 5 ft/min a first roughing cut to remove 0·060 in. on diameter would be followed by another two cuts each to remove 0·030 in. The grinding wheel would then be re-trued and its speed stepped up to about 6300 s.f.p.m. The speed of the work would be reduced to 2 ft/min and a further two cuts, each to remove 0·006 in. from the diameter, would be taken. After another re-truing of the grinding wheel a final finishing cut of 0·001 in. would complete the thread grinding.

It will be noticed that in the "roughing" operation the wheel speed is decreased and the work speed increased. This enables a "coarse-grained" or "soft" cutting action to be obtained, which is conducive to a high rate of stock removal at the expense of errors in the thread form. Such errors, however, are of no immediate concern in the "roughing" process. For the finishing cuts the wheel speed is increased and the work speed decreased so that a "harder" cutting action is obtained. This conduces to the maintenance of the correct thread form on the grinding wheel.

A floor-to-floor time of about twelve minutes would be reasonable on a job of this type.

Fig. 40 (*c*). This is a lead screw, i.e. a job on which accuracy of pitch is essential.

COMMENTS

This is a long, slender screw with a comparatively deep thread form. To counteract "springing" of the workpiece, and to prevent its "flexing" due to its own weight, it would be advisable to use steadyrests.

A three-point steady could usefully be positioned to support the central unthreaded part of the shaft. Two two-point steadies could be used to support the threaded portion.

A considerable amount of side pressure against the leading edge of the wheel is developed during the grinding operation. Under these conditions a progressive pitch error arises, and this increases as the side pressure and resultant flexing of the wheel increases. It may be necessary to repeat the final finishing cut a number of times, so as to ensure that the "thicker end threads" are ground to correct dimensions. During this job the operator will observe that the density of sparks increases towards the end of the work traverse.

Conclusions Summarized. Vitrified wheels should be used for thread grinding calling for a high degree of accuracy in pitch, lead, form, and surface finish; for all threads which have been pre-cut; all long and slender work where springing arises; for worm and hob threads of coarse pitch and deep form necessitating many cuts during which side pressure is prevalent.

Resinoid wheels should be used for mass-production grinding, where tolerances are liberal and the maximum amount of stock must be removed in the minimum number of cuts.

CARE OF GRINDING WHEELS

Storage. It is recommended that grinding wheels be stored in a

bin, or on a rack, specially constructed for the purpose. The wheels should lie flat on their sides with a cushioning layer of corrugated cardboard or similar compressible material.

Grinding wheels should not be stored upright, as any absorbed moisture, such as grinding-oil, will sink to the lower part of the wheels and throw them dangerously out of balance.

The storage room should be dry, and kept at a reasonably constant temperature.

Handling in the Shop. The operator should constantly bear in mind that grinding wheels are fragile. Even small nicks in the wheel

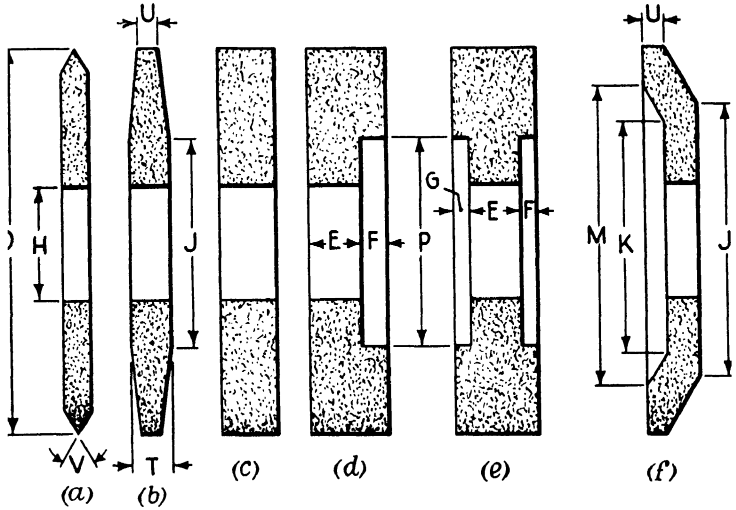


FIG. 41. STANDARD GRINDING-WHEEL SHAPES

Type (*a*). Straight wheel with bevelled edge.
Type (*b*). Tapered two sides.
Type (*c*). Straight wheel.
Type (*d*). Recessed one side.
Type (*e*). Recessed two sides.
Type (*f*). Dish wheel.

KEY TO LETTER DIMENSIONS

D, Diameter (over all).
E, Thickness at hole.
F, Depth of recess (see type (*d*)).
G, Depth of recess (see type (*e*)).
H, Hole.
J, Diameter of outside flat.
K, Diameter of inside flat.
M, Large diameter of bevel.
P, Diameter of recess.
T, Thickness (over all).
U, Width of edge.
V, Angle of bevel.

cause it to run out of balance, cause erratic surface finish, and tend to damage the diamonds. Heavy objects should not rest on or against grinding wheels. Any stacking of wheels must be done carefully, with few wheels per stack.

Inspection. Immediately on receipt of new grinding wheels they should be inspected to see whether damage has been caused in handling or in transit. If a wheel is held loosely and lightly tapped with a block of wood, an indication of its condition can be obtained. A cracked wheel does not emit a clear sound; a wheel with absorbed moisture emits a deadened sound. Resinoid wheels when tapped do

not emit such a clear note as vitrified wheels. If doubt exists as to whether or not it is free from cracks it should be returned for inspection to the manufacturers.

Safety Code. The American Standard Safety Code, "The Use, Care, and Protection of Abrasive Wheels" is obtained from The American Standards Association, 29 West Thirty-Ninth Street, New York, U.S.A., price 35 cents. It is also obtainable from the B.S.I. At the time of writing there is no equivalent British specification.

STANDARD SHAPES. An alphabetic key to proportions and standard shapes of grinding wheels is given in Fig. 41.

CHAPTER VI

DIAMOND TOOLS FOR TRUING AND FORM-DRESSING ABRASIVE WHEELS

THE progress made in thread grinding is due, to a large extent, to the highly specialized work of the diamond industry. Two of the principal difficulties that had to be overcome in the development of the process of thread grinding were (1) the provision of suitable abrasive wheels, (2) the provision of means whereby these wheels could be dressed with formed vee peripheries. Diamond-tipped tools comprise the only practicable means of accurately forming and truing abrasive wheels. The diamond tips are manufactured to a high degree of precision in the angular form and with accurate radii for thread forms with a controlled radius, such as in the Whitworth series, and width-of-flat dimensions as in the Metric, and similar forms of thread.

THE DIAMOND. The diamond is the hardest material known, its property of hardness being similar in many respects to that of crystallized carbon.

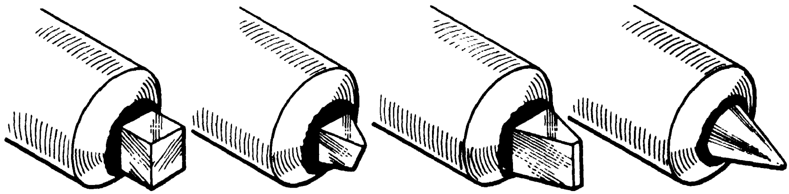
Most of the diamonds used in the engineering industry are mined in the Belgian Congo, Portuguese Angola, Brazil, and British Guiana. The "industrial group" of diamonds are stones of gem quality but inferior in colour, shape, grain, etc. An idea of the extent of the worldwide demand for industrial diamonds at the present time can be gauged from the fact that in 1940 the industrial market absorbed eight times the quantity it absorbed in 1910. There is an extensive demand for *diamond dust* which is used in the manufacture of impregnated wheels, lapping blocks, abrasive powders, special polishing pastes, etc.

The designs and uses of diamond tools are almost without limit, but speaking generally the diamond wheel-dressing tools used for thread grinding are of two types, viz. those employing *formed diamonds* and those employing *unformed diamonds.* These are sometimes referred to respectively as *finished diamonds* and *unfinished diamonds.* Examples are shown in Figs. 42 and 43.

The cutting, polishing, and setting of diamonds is, of course, the work of a specialist and nowadays it is uneconomical for the user of diamond tools to undertake the task of re-lapping and setting the diamonds.

MANUFACTURE OF DIAMOND TOOLS. The diamonds are carefully graded for weight, size, quality, etc., and prepared for setting into the tool after being split, polished and lapped to the shape required. The diamond tools are made very accurately, optical projectors being used throughout the production operations, as well as in the final inspection. The tool "bit," which is usually in the form of a soft-steel rod, is drilled at its end with a drill equal in diameter to the thickest part of the diamond and deep enough to allow about two-thirds of the

diamond to be embedded in the holder. The diamond "chip" is inserted in the hole into which it can be secured by one of four principal methods, viz. (1) brazing, (2) casting, (3) powder metallurgy, (4) induction heating. Probably the oldest and best-known method is *brazing.* Before the actual brazing operation is commenced some of the metal of the holder is peened or forced over against the diamond so as to hold it in place whilst an easy-flowing spelter or hard solder is applied. Slow heating of both tool and diamond is done by means of an oxy-acetylene torch.



CUBE CHISEL 'VEE' CONE

FIG. 42. FORMED DIAMOND TOOLS FOR FORM DRESSING

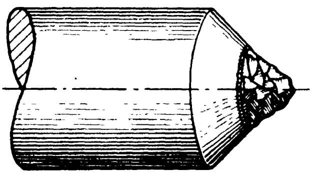


FIG. 43. DIAMOND TOOL FOR WHEEL TRUING

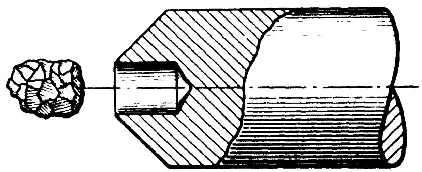


FIG. 44. DIAMOND TOOL ASSEMBLY

In dressing wheels for thread grinding it is essential to have a well-centred diamond and for this reason some experts prefer to secure the diamond in the tool by the *powder metal* or *casting* methods.* Whatever the method employed the finished tool stone is set in its metal holder with great care and accuracy. The operation calls for long experience and a high degree of skill.

THE USE, CARE, AND PROTECTION OF DIAMOND TOOLS. In thread-grinding operations frequent dressing of the abrasive wheel is essential, the actual frequency being dependent on several factors, but principally on (1) the performance of the grinding wheel, (2) the tolerances allowed on the workpiece, in respect both to diameters and to thread form.

To enable efficient dressing of the wheel it is essential that the diamonds be in good condition. They must be sharp, correctly assembled in the tool-holders, and in use should always have a liberal supply of coolant.

* Described in detail in *Securing Diamonds in Wheel-dressing Tools,* by H. L. Strauss, Jr., *Machinery* (*N.Y.*). Vol. 51, 1945, p. 179 (Jun.). Abstracted in *Industrial Diamond Review,* Dec., 1945, Vol. 5.

Operators may be interested to know that if a diamond is heated up to about 750° C., its surface material begins to combine with the oxygen in the air, so forming carbon di-oxide (CO_2). Without a copious supply of coolant this temperature can easily be reached with resultant ill-effects which shorten the life of the diamond. As an introduction to the next paragraph it may be noted that the diamond is a bad conductor of heat. From this it follows that if the extreme operating point is heated up rapidly there may be a steep temperature gradient between the front and back of the diamond, a condition very conducive to fracture.

If the diamond tool commences its cutting operation before the coolant has been applied, it should immediately be removed from contact with the wheel and allowed to cool. Blueing of the metal holder is a sure sign of insufficient cooling. If the coolant is applied while the diamond is hot, the sudden change in temperature may fracture it. The flow of coolant should be directed on to the diamond and *not* on to the metal holder.

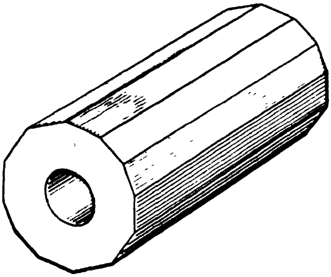


FIG. 45. MULTI-POSITION HOLDER FOR DIAMOND WHEEL-TRUING TOOL

Dulling of the diamonds occurs more readily with hard wheels than with soft—whether they be resinoid or vitrified wheels. A dulled diamond tends to glaze the wheel.

Diamonds which are used when in a dulled or blunt condition may deflect the wheel and in extreme cases will contribute to wheel fracture. Dulled diamonds cut with a high-pitched whistling tone; sharp diamonds cut with a soft low-pitched tone.

Unformed diamonds, when dull-edged, should be rotated in their holders so that they may present a keener cutting edge. A multi-position holder, similar to that shown in Fig. 45, has advantages inasmuch as it allows an even distribution of wear and has a self-sharpening effect upon the diamond.

More fastidious care is necessary with formed diamonds. They must be replaced after considerable use. Beneficial results are obtained by using slightly-worn diamonds for roughing-out the wheel form, and reserving the use of diamonds in better condition for finish-dressing. The actual work imposed upon the diamond should be reduced to the minimum consistent with efficient dressing of the wheel to the correct thread form.

As an example it may be noted that the Ex-Cell-O Corporation, makers of well-known thread grinders, recommend that, to obtain maximum diamond life, the amount dressed off the wheel should be as little as necessary to hold the form. On straight-thread forms they consider 0·001 inch on the wheel diameter usually sufficient as a maximum. On radius forms they consider the amount removed should not exceed 0·0005 inch on the wheel diameter. As to dressing feed they recommend that it should not exceed 0·001 in. per revolution.

In general machine-shop grinding it is common practice to true wheels of moderate size at their proper grinding speeds. Formed

wheels used for thread grinding require reduction of speed during the truing process.

Care should be taken to avoid further truing when the wheel has already been correctly formed. Such further truing is a work of supererogation leading to unwarranted wear of the diamonds.

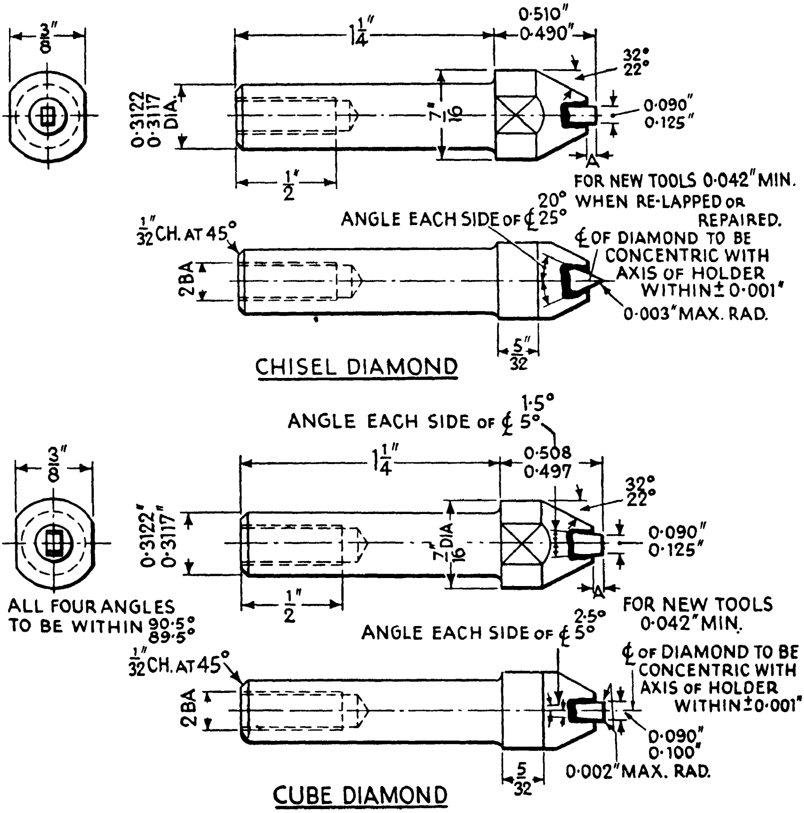


FIG. 46. DIAMOND TOOLS FOR NEWALL GRINDING MACHINES

NOTES. Chisel diamonds for B.A. threads must be selected with an included angle of less than 47° 30′. The holders are mild steel, machined all over. When ordering these tools the length of projection must be stated. This involves the dimension A.

Length A is as follows: For B.A. threads, 0·042 in. to 0·055 in.
For threads up to and including 26 t.p.i., 0·055 in. to 0·085 in.
For threads from 26 t.p.i. up to and including 12 t.p.i., 0·085 in. to 0·120 in.
For threads from 12 t.p.i. up to and including 6 t.p.i., 0·120 in. upwards.

Auxiliary hand-dressing attachments are advised for removing the bulk of unwanted material from new wheels and when changing the form of thread on old ones. In all cases it is a good maxim to use diamonds which are as heavy as possible.

The serviceable life of a diamond is considerably shortened if it is used on unbalanced wheels. Many light cuts at high speed give a far

better truing performance and longer diamond life than results from fewer but heavier cuts at slow speed. "Take light cuts and often."

A chattered work finish may result from using diamond tools which are insecurely clamped in the tool-holders, or be due to diamonds which are loose in their seatings. When properly set and used with

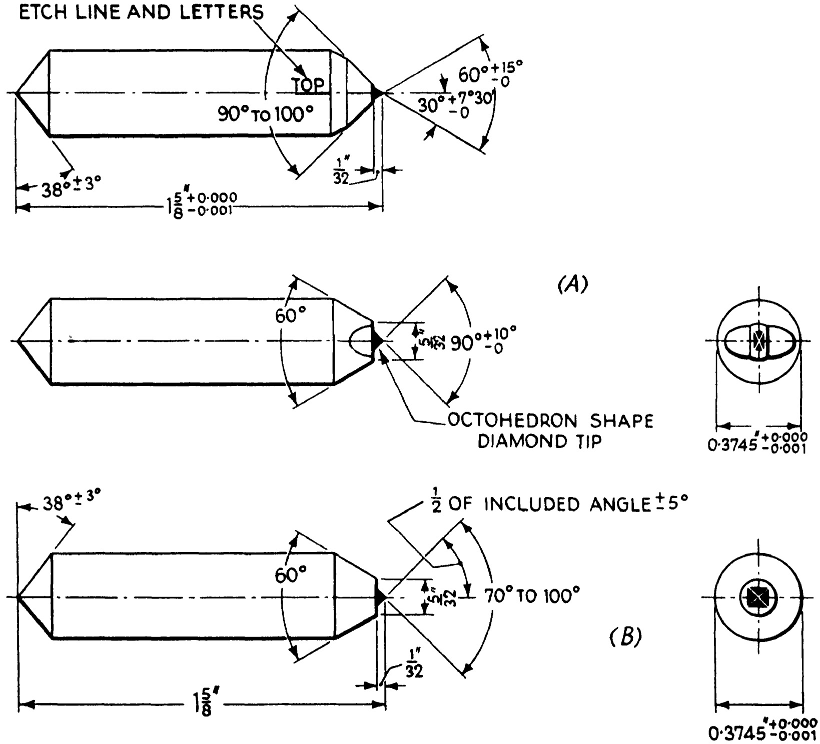


FIG. 47. DIAMOND TOOLS FOR EX-CELL-O THREAD-GRINDING MACHINES

(A) For Radius-form Threads, (B) For Straight-Line-form Threads. Both used in Cam-type Dresser.

NOTES. In both types the pointed conical ends remote from the diamonds are smoothly finished and cyanide cased to a depth of 0·010 in.

In A, the diamond point must be central with axis within 0·001 in.

In B, the octohedron-shape diamond point must be concentric with 0·3745 in. shank within 0·003 in.

ample coolant, it is unlikely that a good stone will become loose in its seating. If any doubt exists about the security of the diamond it should be taken out of service immediately and sent for re-setting and re-lapping. Unless this is done, a sudden jolt may cause the loss of the diamond.

It is worth repeating that where there is scope for selection it is wise to employ a diamond as heavy in weight as is consistent with good results. When the diamond has lost much of its original weight due to wear and tear, relapping, etc., it should be transferred to lighter duties.

Suitable containers should be used for storing diamond tools and records should be kept in respect of all these tools showing the work-hours, speeds, and depths of cuts involved in their use. A moulded rubber cap slipped over the diamond and the end of its holder serves as a protection against accidental blows. So, too, does a short length of rubber tubing.

Holders, as well as diamonds, require thoughtful use. The operator should avoid grinding the metal near the setting, as this tends to loosen the diamond and so paves the way to its fracture.

CHAPTER VII

COOLANTS AND LUBRICANTS

THE selection of the most suitable coolant or lubricant in thread-grinding operations is equally as important as choosing a suitable abrasive wheel or selecting the best combination of speed and feed. The use of an unsuitable grinding oil can be the prime source of difficulty in obtaining accuracy and high surface finish in the product.

Cutting fluids are used in a great range of machining operations and for various excellent reasons, primarily *to dissipate heat* generated in the machining process, both in the cutting agent and the workpiece, as well as to *lubricate* the tools and the work. In such accurate work as thread grinding it is most essential to avoid undue heating, for it causes measurable expansion of the workpiece as well as shortcomings in surface finish. Well-selected coolants and lubricants assist the production of thread-ground workparts with good surface finish and enable full advantage to be taken of high grinding speeds and maximum depths of cut with minimum power consumption.

Before attending to the detailed hints on the choice of cutting fluids for various thread-grinding operations many readers may find it useful to peruse the following summarized information on cutting fluids generally.

CUTTING FLUIDS GENERALLY

(1) **Water Solutions of Alkalis.** As water runs freely, is cheap, and has a high specific heat (higher than any oils), it could be used as a *coolant*. An objection to its use is that it causes rusting. To overcome this objection many *water solutions of alkalis* have been introduced. These water solutions are sometimes termed *soda-water mixtures* and may consist of water with the addition of some soluble alkali ingredient, such as borax, washing soda, sodium silicate, sodium resinate, etc., and perhaps also of a little soft soap to give "body" to the mixture and give it some lubricating property also. The use of a *soda-water mixture* (a typical *alkaline solution*) as a coolant in thread-grinding work is not recommended, if only on account of the danger of injury to the hands and eyes of the operator. As an introduction to the next paragraph it may be noted that water (the simplest *coolant*) can be changed into a *lubricant* by the addition of *soluble oil.* Except for some coarse-grinding operations alkaline solutions have nowadays largely been superseded as cutting fluids by cutting oils having pronounced lubricating properties.

(2) **Emulsions.** An emulsion has been defined as *a milky composition produced by uniting oil and water, through the intervention of some alkaline or mucilaginous substance.*

Emulsions used as cutting fluids consist of tiny particles of oil suspended in water. They may, for instance, be mixtures of water and mineral oils containing oil-soluble emulsifiers like soft soap. Emulsions flow freely, are comparatively cheap and, inasmuch as water has a higher specific heat than any oils used as cutting fluids, they are more efficient than oils as coolants. They are superior to water solutions as lubricants but are inferior in this respect to oils. Note that *soluble oils* are emulsifiable with water and that a satisfactory soluble oil is readily miscible with water to form homogeneous non-separating emulsions.

(3) **Cutting Oils.** Oils are used as cutting fluids with the idea of lubricating, of cooling, and of improving surface finish. Lubrication is their primary function.

They may be classified as (1) *Fixed or organic,* (2) *Mineral,* (3) *Blended.*

Fixed or organic oils are derived from organic sources, e.g. from animals, fish, vegetation, etc. Among them are lard oil, fish oil, cottonseed oil, rapeseed oil, turpentine. They are sometimes called "fatty oils" and in general use are superior as lubricants to the mineral oils. However, they are more expensive and tend to deteriorate more quickly. When they decompose they are likely to give off offensive odours. The instability of fatty oils under high-temperature service conditions is proverbial.

Mineral oils are usually obtained from petroleum. A pure mineral oil is a good lubricant, but much inferior in its cooling capacity to water. It is less expensive than an organic oil. As to "oiliness," a mineral oil is very inferior to a fatty organic oil, such as lard oil. Firms specializing in the production of mineral oils supply them in a range of viscosities. The mineral oils are the simplest "straight" cutting oils; mainly used for light duties and for the more difficult operations on non-ferrous metals where soluble oils cannot be used.

Blended, or compounded, oils are obtained by mixing fixed with mineral oils, e.g. a greater degree of oiliness is obtained by blending lard oil with mineral oil. Other ingredients used with mineral oil are olein and triolein, both of which are obtained from glycerine or from fats.

Sulphurized Oils. Fixed or mineral oils may be "sulphurized" by the incorporation of sulphur, or they may be mixed with an organic sulphur compound. Chlorine additions are also used. These additives increase the film rupture strength of the oils and render them more efficient as lubricators when working on tough ferrous materials where it is essential to obtain both accuracy and good finish. Most of the sulphurized oils used as cutting fluids are manufactured by treating mineral and other oils with organic sulphur compounds, varying the sulphur content of the oil to suit the particular machining process in view. An average of about 2 per cent of sulphur can be taken as a representative figure.

VISCOSITY. The viscosity of an oil may be taken as *its resistance to flow* or *its measure of internal friction.** It is determined by the time taken, in seconds, for a given amount of oil to flow, at a prescribed temperature, through a tube of known length and bore diameter.

A *thick oil* is *viscous*, i.e. has high viscosity; a thin oil has low viscosity.

The instrument largely used in Great Britain for measuring viscosity is called the *Redwood Viscometer*. In the U.S.A. the Saybolt Viscometer is widely used. As changes in temperature cause changes in viscosity, any given viscosity value is stated with the temperature in degrees and the time in seconds. The viscosity of cutting fluids range from 100 to 200 seconds (Saybolt) at 104°F. It may be noted that a low viscosity oil has a greater thermal transference than a more viscous oil, though they may have exactly the same specific heat. Again, two cutting oils may have the same viscosity value but have different degrees of oiliness. By *oiliness* it is meant that property of an oil that causes it to adhere to a metallic surface.

COOLANTS AND LUBRICANTS USED IN THREAD GRINDING

Coolants, in the following notes, may be taken as emulsions formed by the admixture of water and soluble oil or paste.

* A more precise definition of the viscosity of a fluid, explained in textbooks on *Properties of Matter*, is that it is a property measured by the tangential force required to maintain a relative velocity of unity between two parallel planes in the fluid at unit distance apart. Prof. H. Addison states that the viscosity of a fluid is a characteristic property which determines its rate of flow. He also defines it as the property in virtue of which the liquid resists any deforming force, and states that it gives a measure of the reluctance of the liquid to yield to shear.

Lubricants may be taken as oils or pastes which will not emulsify with water. Due to their greater degree of *oiliness* they are more efficient than coolants for producing ground work with a bright and smooth surface. As previously mentioned, they are less efficacious than soluble oils in regard to cooling properties.

In mass production work, where one machine is arranged to rough-out the work and a second machine is set-up for finishing the work to the required size, it is not unusual for the first machine to be supplied with a soluble coolant and for the second machine to use a lubricant, or what is sometimes referred to as a "straight" cutting oil.

In the notes that follow, the term "coolant" refers to a mixture with a high percentage of water, say 85 to 95 per cent; and "cutting-oil" to an emulsion of approximately equal quantities of water and soluble oil. References to "lubricant" imply a non-soluble oil; the term "grinding oil" is to be taken as meaning all three. Many proprietary brands of grinding oil are manufactured, in some instances having been developed solely for use in thread grinding. The selection of the most suitable grinding oil for any given job is, of course, a matter which has to be decided in relation to many factors and conditions peculiar to the job and the equipment available. In cases not covered by the following notes the operator may usefully apply for guidance to the firms specializing in the manufacture of grinding oils.

Thread-ground Work of Tool-room Class. This varies widely in regard to the nature of the material to be ground, the size and shape of the thread, the quantity required of work parts with similar dimensions, etc. In this class of work it is usual to employ a "general purpose" grinding oil. Sperm oil gives good results but is expensive initially. See previous notes on *Fixed or organic oils*. Soda-water mixtures are sometimes used, but are not recommended. See previous notes on *Water solutions of alkalis*. Grinding without the use of a cutting oil is sometimes carried out but is not conducive to good production.

For Mass Production Work the following notes will assist in selecting a cutting fluid.

(1) **High Speed and Deep Cut.** Used mostly for roughing-out operations where a good surface finish is not of such importance as obtaining the maximum depth of cut at the highest practicable cutting speed. In such cases the fluid must have good cooling properties, hence the use of a soluble coolant with a high water content is suggested.

(2) **High Speed and Shallow Cut.** This is associated particularly with the operation of "finishing to size" and requires a *lubricant* for producing a smooth and bright surface finish.

(3) **Low Speed and Shallow Cut.** Does not require much cooling, hence the property of lubrication will over-ride that of cooling. A high viscosity *lubricant* would be required.

(4) **Low Speed and Deep Cut.** This requires both cooling and lubrication and a *soluble oil emulsion* is recommended. The ratio of

water to oil depends upon the relative importance of cooling (in relation to speed used) and of lubrication (in relation to the kind of surface finish desired).

Desirable Properties of a Good Grinding Oil are as follows—

(1) *It should have high thermal conductivity* to ensure that the heat generated during grinding is immediately dissipated, leaving a film of oil on the wheel and the work with good lubricating effect.

(2) *It should not readily oxidize* and develop gumming deposits with resulting injury to the bearings and slides of the machines.

(3) *It should not be unpleasant in odour* after continued use or when heated.

(4) *Generally*, in addition to its hygienic and anti-rusting properties, the oil should facilitate separation of the floating abrasive dust, scum, and metallic particles so that the latter are not continuously pumped through the supply system. The flash point of the oil should exceed 300° F.

If different grinding oils are experimented with two possible causes of trouble to be looked for are (1) *fire*, due to spontaneous combustion, (2) *infection*, due to high acidity or contamination. It may be added that the percentage of free fatty acid (determined by physical and chemical analysis) gives a reliable indication of the bacterial content and rancidity and should on no account be allowed to exceed 3 per cent, otherwise there is risk of dermatitis.

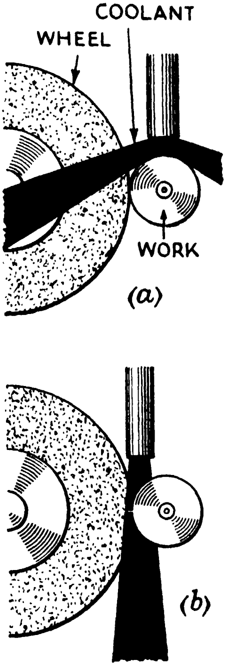


FIG. 48. APPLICATION OF GRINDING OIL

Application of the Cutting Fluid to the Work. To take full advantage of the higher cutting speeds and feeds and of the abrasive wheel selected for the particular job in hand, it is essential to direct the flow with care. Another point to bear in mind is that the fluid should be used as economically as possible consistent with efficiency. Much oil wastage is traceable to faulty design and mounting of the nozzle—a common cause of excessive spray and splashing.

The grinding oil should be delivered, in sufficient volume as near as possible to the area of contact of the workpart and the abrasive wheel, so as (1) to dissipate the heat effectively, (2) to wash away the abrasive dust which wears off the wheel, (3) to wash away all swarf, chips, and particles of material removed by the grinding wheel, (4) to provide a film of oil to lubricate the zone of "cutting contact."

In Fig. 48 (*a*) is shown a common error in positioning the nozzle. This gives the operator the impression that the grinding oil completely covers the work, whereas burning and excessive sparking may be occurring with accompanying poor quality surface finish and rapid wearing of the wheel. By readjusting the position of the nozzle, as shown in Fig. 48 (*b*), the bulk of the grinding oil is enabled to reach that part of the work where the heat is generated.

The cross-sectional area of the nozzle should be large enough to allow an ample flow at low velocity. A high-velocity stream of grinding oil pumped through a small orifice is usually less effective than appears and is conducive to oil wastage by excessive splashing and oil-spray. The volume of coolant should, however, be at least 5 gal. per min.*

The nozzle and pipe-lines should be free from leaky joints so that no foaming of the grinding oil will develop, and the volume should not fluctuate.

Temperature. The storage and settling tanks should be large enough to assist in maintaining the oil in a cool state. Obviously

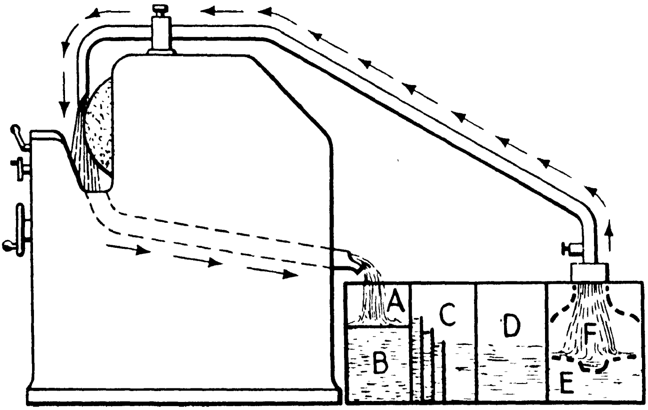


FIG. 49. SCHEMATIC ARRANGEMENT OF "COOLED COOLANT" CIRCUIT

A : Magnetic swarf trap.
B : Filtration chamber.
C : Weirs and settling chamber.
D : Refrigerator.
E : Reservoir.
F : Coolant return pump.

a supply of warm grinding oil is devoid of useful cooling effect. Some manufacturers provide refrigeration appliances in the supply circuit. A "cooled coolant" arrangement is shown in Fig. 49.

Cleanliness. Frequent cleaning of the storage tank, weirs, strainers, and filters is essential; surface scum being removed daily. All pipes and nozzles should be scoured and rinsed every few months.

It is good practice to arrange magnetic filters in the liquid return circuit to separate the metallic and abrasive sediment from the liquid. The filters are readily scraped free from swarf. Excess abrasive "sludge" and metal particles in the storage tanks causes loading of the grinding wheel and scratching of the ground surface. Where excessive stock removal is being carried out the necessity to filter the grinding oil is accentuated.

Infection. Some proprietary cutting fluids of the less dependable and cheaper kinds are prone to rancidity, and the development of

* As an example, it may be mentioned that on the *Newall Thread Grinder—Model* 836, coolant is supplied by an electrically-driven centrifugal pump at the rate of 18 gal per min.

objectionable odours. Furthermore they are culture beds for pathogenic organisms. Whilst the addition of deodorants has little real effect, the addition of suitable disinfectants is an advantage. Thus, when mixing emulsions it is common practice to add a phenol or carbolic acid disinfectant to the extent of 1 gal of disinfectant to 1000 gal of emulsion. Septic wounds and skin diseases have been traced to infections caused by cutting fluids which had become contaminated and allowed to go too long without purification and renewal.

Skin diseases may be contracted by operators although the cutting fluid is not infected bacteriologically—due to the mixture of oil and abrasive dust plugging up the glands of the hair roots. Operators should apply an antiseptic lotion to their hands and arms before commencing work. Care should be taken not to wipe hands and arms with oily rags bearing particles of metal and abrasive dust. Slight cuts may develop into septic wounds if the cutting compound is contaminated.

CHAPTER VIII

WHEEL PROFILING WITH DIAMOND TOOLS

DIAMOND tools are used for truing, forming and dressing grinding wheels on thread-grinding machines. The manner in which the tools are used for truing is similar to that used in truing grinding wheels on more conventional grinding machines.

USE OF DIAMOND TOOLS. Three distinct operations are entailed in the use of diamond tools for thread-grinding operations. They are: (1) truing, (2) forming, (3) dressing. To avoid confusion that may arise in the use of such terms the following explanations are given.

(1) **Wheel Truing.** This term refers to the use of a diamond tool or tools for cutting away such portions as cause grinding wheels to rotate unevenly or "out of truth."

(2) **Wheel Forming.** This term refers to the use of a diamond tool or tools for forming, by cutting, one or more grooves or ribs of prescribed shape and size on the peripheral faces of grinding wheels.

(3) **Wheel Dressing.** This term refers to the use of a diamond tool or tools for maintaining accuracy in shape and size of grooves already formed on the peripheral faces of grinding wheels.

Wheel-forming and wheel-dressing operations are usually jointly referred to as "form-dressing."

WHEEL TRUING. This operation entails the use of a diamond tool which is caused to traverse across the face and sides of a grinding wheel as the latter rotates. The truing operation may be split into two parts, the first being rough truing, the second being finish truing. It is customary to balance the grinding wheel after the rough truing and before the finish truing operations. The rate of traverse of the diamond tool influences the depth of cut that can be maintained without impairing the efficiency of the diamond. In addition, the speed, hardness, and grit size of the wheel are other factors which must be considered in both the selection and use of diamond tools.

Diamond Tools for Wheel Truing. In the wheel-truing operation the diamond tool is not used to cut the wheel into any complicated shape, but simply to produce a flat face and flat sides. Thus an "unformed" or "unfinished" diamond is suitable.

The general rule of using as large a diamond as practicable for wheel truing is commendable if only because heat conductivity increases with increase in size of diamond. Nevertheless, a closer control of diamond tool expenditure is maintained by selecting a diamond by reference to (1) its weight, and (2) particulars peculiar to a given wheel. The following table has been included by kind permission of Technical Diamonds, Ltd., Bangor, North Wales. It is helpful when

selecting diamond tools. The selection is based on the weight of the diamond in relation to known particulars of the grinding wheel.

CODE	ROUGH TRUING	FINISH TRUING
10	0·75 to 1·00 carat	0·33 to 0·50 carat
15	1·25 to 2·00 carat	0·50 to 0·75 carat
20	1·75 to 2·50 carat	0·75 to 1·00 carat
25	2·25 to 3·00 carat	1·00 to 1·25 carat
30	2·75 to 3·50 carat	1·25 to 1·50 carat
35	3·25 to 4·00 carat	1·50 to 1·75 carat
40	3·75 to 4·50 carat	1·75 to 2·00 carat
45	4·25 to 5·00 carat	2·00 to 2·25 carat
50	4·75 to 5·50 carat	2·25 to 2·50 carat
55	5·25 to 6·00 carat	2·50 to 2·75 carat
60	5·75 to 6·50 carat	2·75 to 3·00 carat
65	6·25 to 7·00 carat	3·00 to 3·25 carat

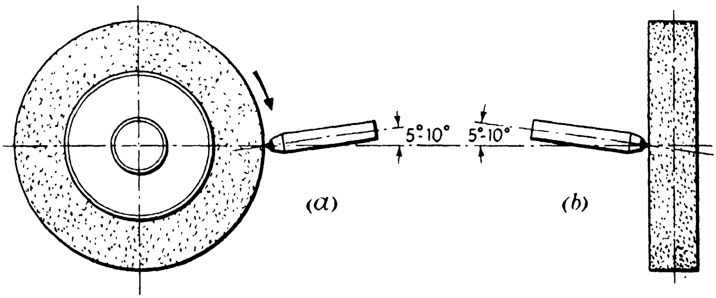


FIG. 50
(*a*) TRUING FACE OF GRINDING WHEEL
(*b*) TRUING SIDE OF GRINDING WHEEL

Constants: Hardness of wheel.—Soft 2; Medium 3; Hard 4. Grit of wheel: Coarse 6; Medium 5; Fine 4.

Add up: Diameter of wheel (in inches), Face width of wheel (in inches), and constants for hardness and grit.

EXAMPLE

Wheel 14 in. × 2 in. Medium Hardness. Fine Grit. This gives 14 + 2 + 3 + 4 = 23. Look for the nearest figure under *code*, i.e. 25. For rough truing use a medium-quality diamond, of 2·25 to 3·00 carat. For finish truing use a good-class diamond of 1·00 to 1·25 carat.

Remember that the larger the wheel to be trued and the harder the bond, the larger must be the diamond to give satisfactory service; the finer the grit, the better must be the quality of diamond.

Mounting the Diamond Tool. First see that the diamond is firmly embedded in its seating and that the diamond tool is rigidly held in its holder. Firmness and rigidity are essential.

The diamond tool should be inclined to the wheel at an angle of between 5° and 10°, as shown in Fig. 50. The object of tilting the tool may be appreciated by likening it to a pencil. If a pencil be used

continuously in a truly upright position then, evidently, the point will rapidly wear, thus necessitating frequent re-sharpening. By tilting the diamond tool and occasionally rotating it in its holder, so as to present a different face to the wheel, we introduce a *self-sharpening of the diamond.* The sharpness of the diamond is prolonged by mounting the tool so that the diamond makes contact *slightly below* the centre of the wheel.

When a diamond is used under abnormal conditions fracture may result. Such fracture occurs more readily when the diamond is so positioned that its grain is in line with the direction of rotation of the grinding wheel, for it is fairly easy to split a diamond along its grain. Therefore, it is beneficial to mount the diamond tool so that the grinding wheel rotates crosswise to the grain of the diamond.

Patented diamond tools are supplied by Technical Diamonds, Ltd. The shanks of these tools are marked with four red spots so placed that when opposite spots are in line with the rotation of the wheel the latter rotates *against* the grain of the diamond. This not only ensures a reduction in the possibility of breakage, but also increases the life of the diamond.

Truing Speeds and Depth of Cut. For rough truing operations a diamond traverse speed of between 10 and 20 in. per min gives best results under average conditions. For finish truing this speed should be reduced to about 6 in. per min.

The depth of cut for rough truing should not exceed 0·005 in. but this, of course, is dependent on the condition of the diamond and the hardness of the grinding wheel. For finish truing the depth of cut should not exceed 0·002 in.

It is beneficial to reduce the speed of the grinding wheel to about one-half its operating speed for rough truing. This prolongs the serviceable life of the diamond and gives it a free cutting action. It is an added advantage to take the first few finish truing cuts at this reduced speed. The final finish truing should be carried out while the grinding wheel rotates at its normal operating speed. At all times when wheel speed is altered a few minutes' interval should be allowed before continuing truing. This enables the wheel spindle and bearings to stabilize at the changed speed.

Provision is made on some makes of thread-grinding machines for changing the speed of the wheel by electrical control.

WHEEL FORMING. The different methods of forming one or more thread-form grooves or ridges on the peripheral face of a grinding wheel can usefully be grouped under two headings. They are (1) *Copying Methods,* (2) *Generating Methods.* Some methods may be regarded as a combination of copying and generating.

Copying Methods of Wheel Forming

These methods are characterized by "formers" or "templates" (which are similar in shape to the form of thread to be ground), incorporated in the wheel-forming devices. The sizes of such formers are usually a number of times larger than the reproduced forms on the grinding wheels. Thus, any inaccuracies in the formers, or in their

adjustments, are reduced in proportion to the differences between the sizes of the formers and the sizes of the reproduced forms of thread. Examples of copying methods are illustrated and described in ensuing paragraphs.

Direct Form Copying. Fig. 51 shows the *Newall Patented Wheel-dressing Attachment* as used on Newall thread-grinding machines. The principle of this direct "copying method" is the reproduction of a

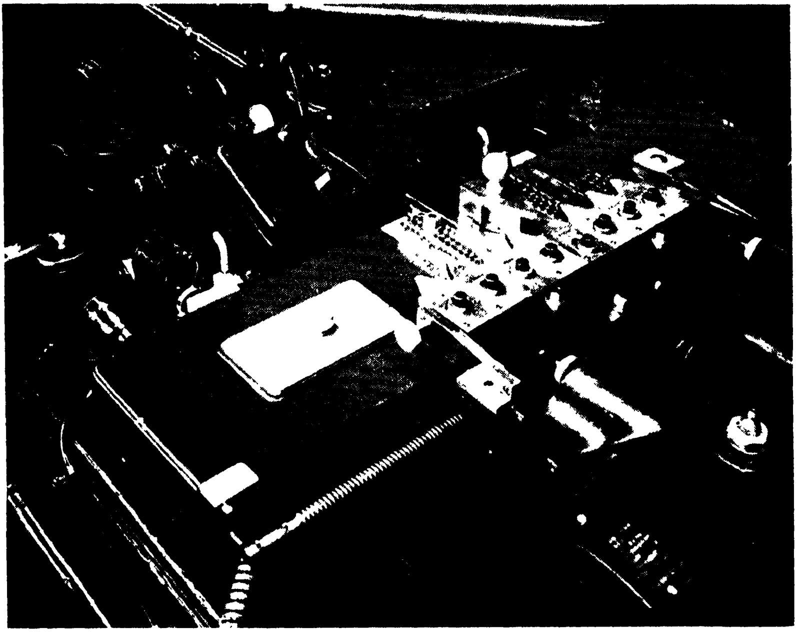


FIG. 51. NEWALL PATENTED WHEEL-DRESSING ATTACHMENT
(*Courtesy of The Newall Engineering Co., Ltd.*)

thread form on the grinding wheel from an accurate *former* mounted in a holder on top of the attachment. The form-dressing mechanism is actuated by a small electric motor causing the *stylus* to follow the outline of the former, this in turn causing a diamond tool to traverse across the peripheral face of the grinding wheel. Thus, the face of the wheel is formed with continuous grooves and ridges of the required shape and size. The dimensions of the stylus and of the former are respectively fifteen times larger than those of corresponding dimensions of the diamond and form of thread to be ground.

When multi-rib grinding is to be employed a multi-rib former is used. When single-rib grinding is chosen a single-form former is used. The operation of the attachment is push-button controlled, the length of traverse being adjustable by positioning limit stops. Threads from 6 B.A. to 6 t.p.i. can be formed by using the standard attachment. The formers are very accurately made, and, due to a

magnification factor of 15 : 1, any slight inaccuracies in the formers, or in their adjustment, are accordingly reduced to one-fifteenth. The stylus, also, is fifteen times the size of the diamond and, to ensure that both are of like form with corresponding radii, an optical projector is usually employed. The form of the stylus can be modified, by filing or grinding, to correspond with the form of the diamond.

In Chapter VI will be found detailed particulars of diamond tools

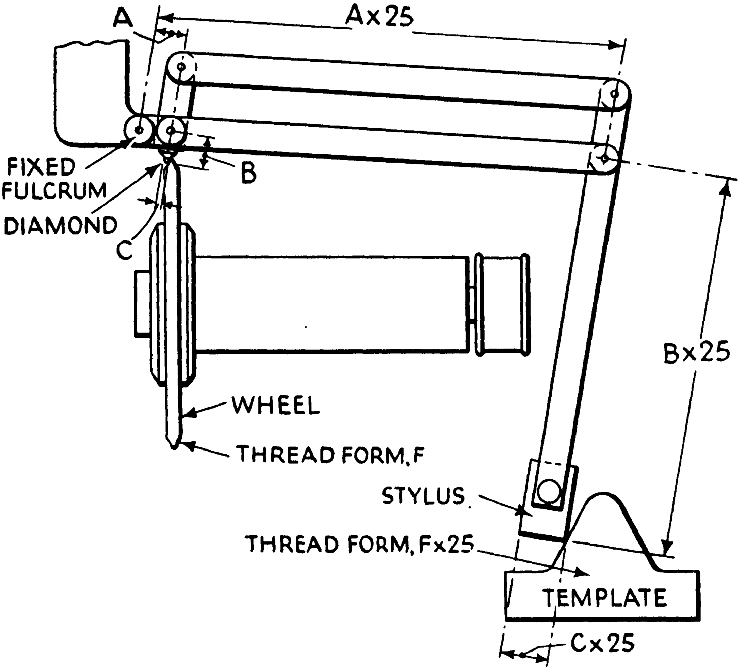


FIG. 52. PROFILING SINGLE-RIB GRINDING WHEEL BY PANTOGRAPH

used with the form-dressing attachment; both chisel and cube diamonds are employed.

Pantograph Method of Wheel Forming. The principle of the pantograph was applied to form-dressing grinding wheels on the original types of thread-grinding machines. The use of pantograph methods dates back to about 1930, synchronizing with the development from thread grinding on modified lathes to the earlier types of thread-grinding machine.

Hardened-steel formers or cams, styluses, and formed diamond tools are used in conjunction with the pantograph. The formers are made to an enlarged scale, the ratio in size of the former and of the required thread being made equal to the reduction ratio of the pantograph. Application of the pantograph method is usually restricted to form-dressing single-rib wheels and shows to particular advantage when

applied to internal thread grinding. Fig. 52 shows the pantograph method of wheel forming from a template 25 times full size.

Ex-Cell-O Pantograph-type Internal Grinding-wheel Dresser. With this unit can be obtained straight as well as radius form threads, such as U.S. Standard, 60° Sharp "Vee," 29° Acme, Whitworth, Modified Buttress, and special forms.

For generating the desired thread form a set of two interchangeable

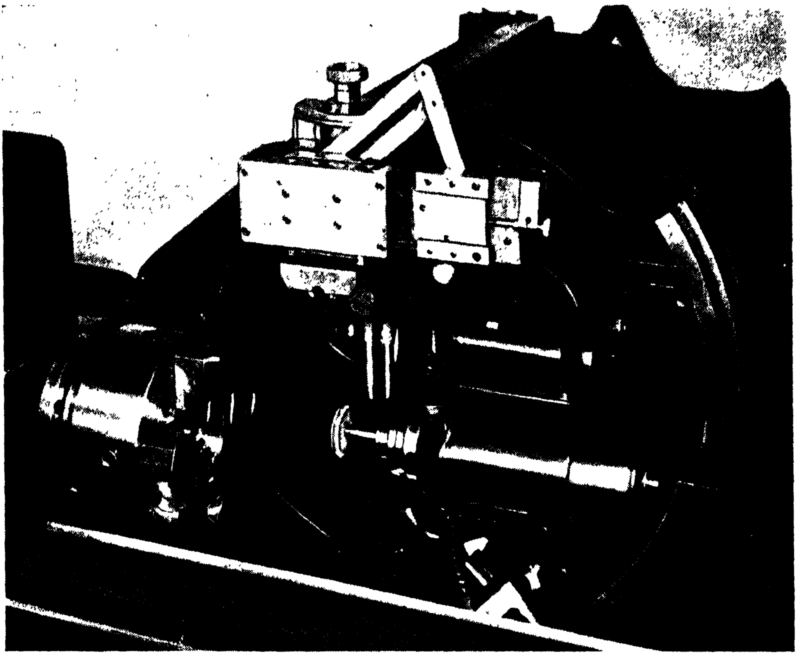


FIG. 53. EX-CELL-O PANTOGRAPH-TYPE INTERNAL GRINDING-WHEEL DRESSER
(Positioned for Grinding.)

cams is required. One set of 60° cams is used for the U.S. Standard and 60° Sharp "Vee" threads, while another set of cams is required if Acme threads are to be ground. For Whitworth or other radius forms it is necessary to have a different set of cams for each thread form. Cams can be supplied to grind threads of any unsymmetrical form that is not less than 5° on the side. A set of cams can be changed on the machine in about five minutes.

Two select natural stone diamonds that do not require special lapping are used. The radius on the radius form threads does not depend on a special radius form lapped on the diamond, but is generated by means of the points on the diamonds. These points are "re-sharpened" while cutting the grinding wheel, eliminating the possibility of a change in the thread form due to wear.

The unit is hinged to the external grinding spindle. During grinding it is swung upwards through 90°, as shown in Fig. 53, and locked in position out of the path of the work and workhead. Fig. 54 shows the unit in position for dressing the grinding wheel. The movement of the two diamonds is controlled by the manually operated pantograph mechanism. Straight-line form cams are used. The desired accuracy of thread form is readily obtained because of the large reduction between the cams and thread form.

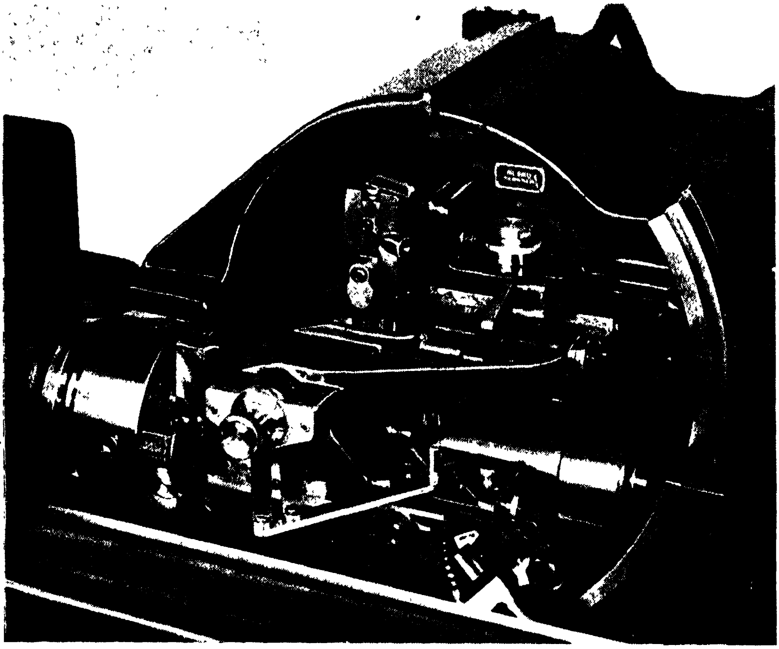


FIG. 54. EX-CELL-O PANTOGRAPH-TYPE INTERNAL GRINDING-WHEEL DRESSER
(Positioned for Dressing.)

Jones and Lamson Pantograph-type Wheel-dressing Unit. This unit, which is used for form-dressing external thread-grinding wheels up to 20 in. diameter, employs two formers and two "formed" diamonds. The radius of the thread form is controlled by the radii of the diamonds, styluses, and formers. One set of two formers is required for each form of thread to be ground. One former and one diamond form one-half of the thread on the grinding wheel, the other half being formed by the remaining former and diamond. The ratio, in size, between the formers and the required thread form is sufficiently large to allow for the desired accuracy of thread form to be obtained by adjustment.

Fig. 55 shows the paths followed by the diamonds.

Generating Methods of Wheel Forming

These methods differ from copying methods inasmuch as no formers

or thread form templates are used. Instead, the generating devices contain one or more generating cams used in conjuction with styluses and diamond tools. In some cases the units are driven directly from the work-driving transmission gearing. The diamond tool or tools receives gradual feed motion, towards and away from the peripheral face of the grinding wheel, through the advance and retard action of the form-generating cam. The diamond tool, or tools, receives axial traverse at the same time as the to-and-fro feed motion. Hence the diamond is caused to trace out the outline of the form of thread

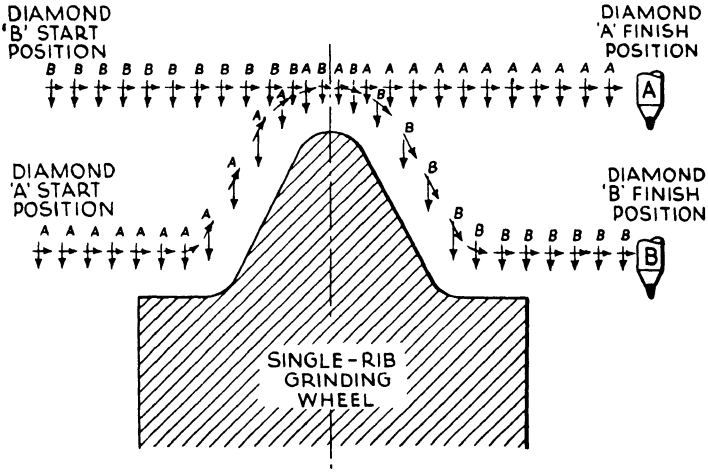


FIG. 55. PATH FOLLOWED BY DIAMONDS IN JONES AND LAMSON PANTOGRAPH-TYPE WHEEL-DRESSING UNIT

to be produced on the grinding wheel from which it is reproduced on the workpart.

Matrix Patent Multi-ribbed Wheel-dressing Device. This incorporates a most ingenious and efficient generating method of forming and form-dressing a series of thread-form ribs on the peripheral face of the grinding wheel. The device, shown in Fig. 56, is mounted between the centres of the machine and is driven by the work-driving mechanism. The form-generating cam, contained within the unit, is given rotary motion as it is driven by the driving peg attached to the faceplate of the headstock. Axial motion of the unit is obtained from the traverse of the worktable. Thus, as the generating cam rotates, it feeds a diamond towards and away from the grinding wheel. At the same time, the diamond traverses across the face of the wheel. The relation between the rate of linear motion and the feeding of the diamond controls the pitch of thread formed on the wheel. The magnitude and rate of advance and retard of the cam, working in conjunction with the stylus and diamond tool, determines the depth and shape of the thread.

A different cam is used for each pitch and form of thread. In addition, a radius-tip diamond tool is selected dependent on the radius of the thread to be ground.

The path of the diamond across the wheel face is shown in Fig. 57.

WHEEL DRESSING. As already mentioned, the wheel-dressing operation follows that of wheel forming. Furthermore, both operations are often referred to as "form-dressing"—the term being an abbreviation for "forming and dressing." The same equipment and methods are used for the two operations. Further information is given in later paragraphs on the essential requirements of form-dressing operations.

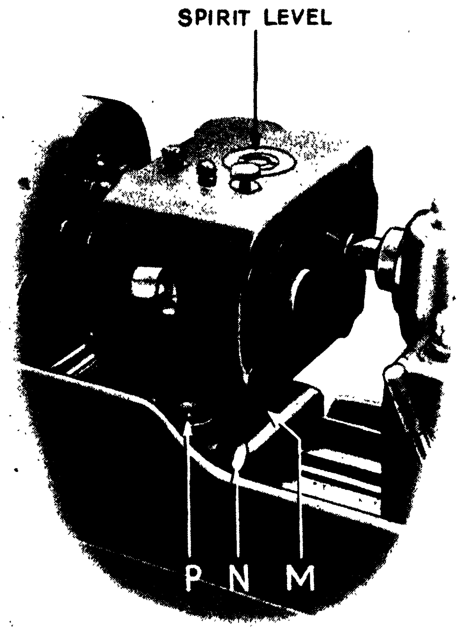


FIG. 56. MATRIX PATENT MULTI-RIBBED WHEEL-DRESSING DEVICE AND JACK MOUNTED IN THE MACHINE

P. Hand-adjusting Nut for Tilting the Dresser.
M. Bracket Carrying the Diamond Dresser on the Table Slides.
N. Hand-locking Nut for *P.*

Form-dressing. Factors which determine success in form-dressing are as follow—

(1) Selection of diamond tools.
(2) Mounting of diamond tools.
(3) Traverse speed of diamond tools.
(4) Depth of cut.
(5) Speed of wheel.

Every factor warrants the most careful attention and it must not be taken that the foregoing list is arranged in order of importance.

Selection of Diamond Tools for Form-dressing. This, of course, has to be carried out with even more care than is taken in the selection of diamond tools for wheel-truing. The accuracy in form of the diamond determines the accuracy of the thread form produced on the grinding wheel. The part of the diamond protruding from the holder, including angle and radius, is lapped to a very high degree of accuracy. An idea of the size of radius on a typical diamond may be obtained by noting that the chisel diamond shown in Fig. 46 has a stipulated maximum radius of 0·003 in. In some other cases, the radius must be less than 0·002 in.

While the many types of diamond tools used in form-dressing are known by their respective names, they all come under the general classification of "finished" or "formed" diamonds. In wheel truing the diamonds normally used come under the general classification of "unfinished" or "unformed" diamonds. Further reference to diamonds is made in Chapter VI.

With different types of machines, different types of diamond tools have to be used, but in all cases it is essential that the diamonds be sharp, otherwise dull cutting surfaces will be produced in the wheel.

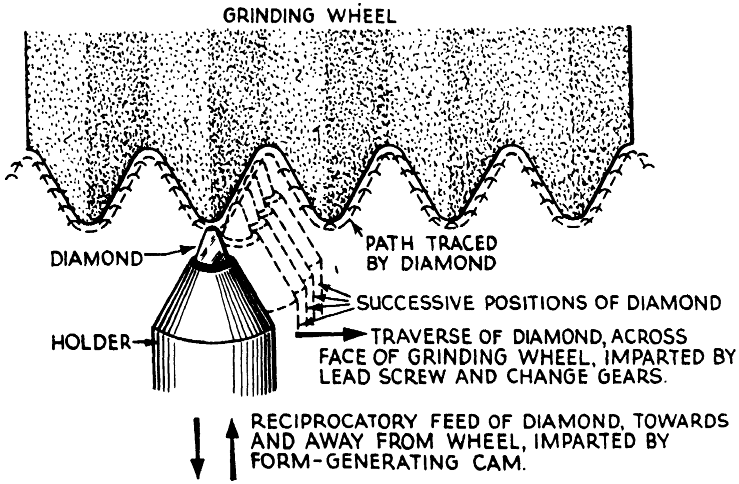


FIG. 57. PATH OF DIAMOND ACROSS WHEEL FACE, USING MATRIX PATENT MULTI-RIBBED WHEEL-DRESSING DEVICE

Radius of Diamond: 26 t.p.i. and Coarser, 0·005 in.; 50 t.p.i. to 26 t.p.i., 0·0025 in.; Finer than 50 t.p.i., 0·002 in.

Traverse Speed of Diamond Tools. No useful purpose would be served by an attempt to state hard-and-fast traverse speeds for diamond tools. Much depends upon conditions peculiar to the quality and usage of the diamonds as well as upon characteristics of the grinding wheels. Furthermore, on many thread-grinding machines such traverse speed is predetermined by the machine manufacturers and is beyond the influence of the operator. However, in some cases the traverse speed is controlled by variable mechanical drives and can be adjusted by using different change wheels.

As a *general* rule, the traverse speed should not exceed 3 in. per min. Of course, the softer the wheel and the sharper the diamonds the higher may be the traverse speed. In all cases, reference should be made to appropriate Operating Instructions.

Depth of Cut. The amount of stock cut from the wheel must be kept to a minimum if wear of diamonds is to be curtailed. A depth of cut of 0·0015 in. is usually sufficient. The softer the wheel the deeper the cut that can be taken. A sharp diamond will, of course, allow of

more rapid stock removal than would be the case with a dulled diamond.

Deeper cuts may be taken when wheel forming. Shallower cuts should be taken when wheel dressing. The final traverse of the diamond should be allowed without any in-feed of the diamond.

Mounting Form-dressing Diamond Tools. It is a necessary preliminary to inspect the diamond tools for accuracy of form, sharpness, and

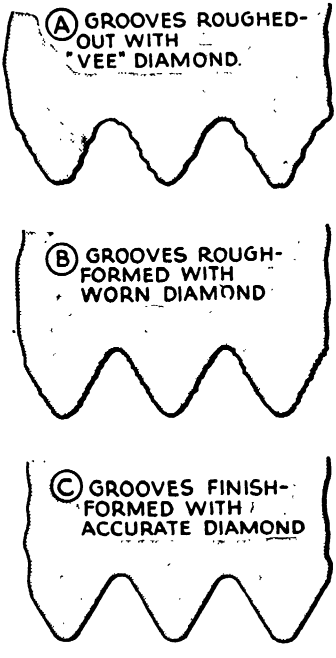


FIG. 58. STAGES IN FORMING AND FORM-DRESSING A MULTI-RIB WHEEL

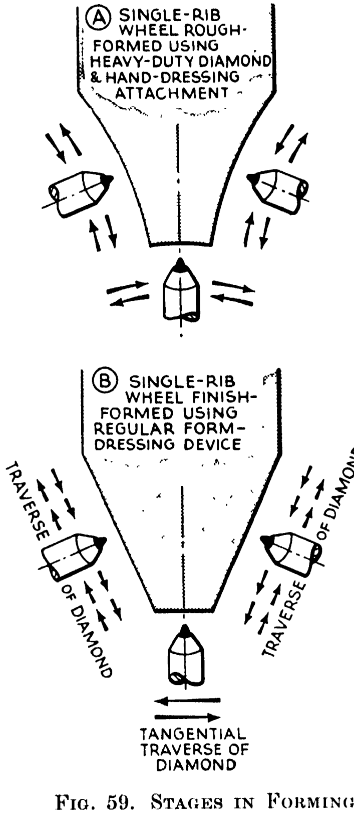


FIG. 59. STAGES IN FORMING AND FORM-DRESSING A SINGLE-RIB WHEEL

general condition before assembling them in their respective holders. Any errors in the form of the diamond will, of course, be reproduced on the grinding wheel and thence on the workpart.

Diamonds must be supported firmly. This requires firm setting of the diamond insert and firm clamping of the diamond tool. If it is not supported rigidly the finish on the workpart will show chatter marks. The position of the diamond tool relative to its operating stylus and cam, or former plate, is in most cases fixed by a prescribed

dimension. To facilitate correct positioning of the diamond tool it is customary for the manufacturer of the machine to supply a setting tool or limit gauge. In addition, optical projection apparatus is often employed to ensure that the diamond tool is correctly positioned.

Resultant errors in the thread-form ground on the product are often found to be due to incorrect setting of the diamond tool. For instance, if the diamond tool be inadvertently positioned above or below the centre of the grinding wheel, errors in contour and depth of thread are unavoidable.

No general rules, applicable to all makes of machines, can be stated for mounting form-dressing diamond tools. In cases where doubts arise it is necessary to refer to appropriate Operating Instructions.

Speed of Wheel. For the wheel-forming operation the speed of the wheel should, generally speaking, be reduced to about half its operating speed. However, the last two or three cuts should always be taken with the wheel rotating at its normal operating speed. Under average conditions, the slower the speed of the wheel the more rapid is the rate of stock removal but, carried to excess, the cutting action will be more akin to "chipping away" the particles of abrasive. The latter conduces to a shortened life of diamond tools together with errors in form of thread.

FORMING AND FORM-DRESSING. Much wear of diamonds can be avoided by completing the wheel-forming and form-dressing operations in three different stages. The first stage consists of plunge-cutting the grooves on the wheel by feeding the latter into a "Vee" diamond which approximates in shape to the form of thread required. The spacing of the grooves is obtained by using the regular table traversing mechanism. The first groove is cut by feeding the grinding wheel into the diamond to the extent of the depth of thread. The wheel is then backed away from the diamond and the latter moved a distance equal to the pitch of thread to be ground. The wheel is again fed into the diamond so as to form the second groove. By repeating this process a number of grooves, which approximate to the form required, are produced in the wheel, The form of thread grooves thus obtained is shown in Fig. 58 (*a*).

In the second operation the first-used diamond is replaced by one which has been used for form-dressing but is of inferior quality due to wear and tear. This second diamond is carefully mounted and matched up with the first roughed-out groove. It is then used to clean-up the grooves by employing the form-dressing device. The form of thread thus produced is shown in Fig. 58 (*b*).

The final forming and form-dressing operations are completed by using an accurately formed diamond. The form of thread grooves on the wheel would then be of correct proportions, as shown in Fig. 58 (*c*).

Manually operated attachments are usually supplied as standard equipment on single-rib type machines and are used to rough-form the wheel, as shown in Fig. 59, the example shown being a wheel formed with extended form of thread. See also Fig. 14 in Chapter III.

It is beneficial in all cases to rough-form the grooves by using diamond tools of heavy-duty type. Furthermore, it is commendable practice to keep particular wheels for grinding certain pitches. Thus, a wheel formed for, say, 10 t.p.i. would be retained for that particular pitch of thread and not re-formed for, say, 30 t.p.i. This practice conduces to economy in time, diamonds, and grinding wheels.

CHAPTER IX

CRUSHING ROLLERS AND THEIR USES

It has been mentioned that steel crushing rollers, or "crushers," can be used as alternatives to diamond tools for forming the peripheries of grinding wheels, especially those of multi-rib type. It is a form-dressing operation suitable for all kinds of thread grinding with the exception of the highest class of precision tools and gauges.

ADVANTAGES OF CRUSHING. One obvious advantage is that it reduces the consumption of expensive diamond tools. The crushing roller is made of hardened and ground steel, its periphery containing a number of grooves or continuous ribs having exactly the same form and pitch as the threads required in the workpiece. These grooves or ribs are ground on a thread-grinding machine by means of a grinding wheel diamond-dressed to accurate form. In addition some rollers have a number of spiral grooves cut along their peripheries, their purpose being to collect grit removed from the wheel. Various materials are used for the rollers, e.g. hardened and tempered carbon steel and tungsten high-speed steel. Carbon steel, of course, is peculiarly liable to lose its temper when subjected to re-grinding. The material must be tough, have good resistance to abrasion, and be able to stand up to service at high temperature if necessary. It may be added, however, that relatively little heat is developed in the usual run of crushing operations.

So that it may rotate freely the crushing roller is usually mounted on heavy-duty ball or roller-bearings carried on a short shaft, itself mounted on a slide so that the roller may be fed into the periphery of the grinding wheel. The crushing method should not be used unless the design of the wheel spindle and bearings is suitable. For instance, it should not be attempted where an "overhung" wheel is mounted at the end of a relatively long spindle, unless precautions are taken to prevent flexure. For this reason crushing is often avoided for internal grinding, although in some shops internal grinding wheels are customarily dressed by crushing.

In some instances, due to absence of special crusher mountings, the crushing roller is mounted on a shaft and the latter held between the centres of the machine.

PLAIN AND GROOVED ROLLERS. Fig. 60 shows plain and grooved crushing rollers as supplied for Matrix thread-grinding machines by the Coventry Gauge & Tool Co., Ltd., who recommend that for all threads finer than 20 t.p.i. the plain roller be used; for all other threads either the plain or grooved rollers are recommended. Hard and fast rules are impossible. Every thread-grinding job must be dealt with individually. When crushing resinoid wheels with a grooved roller, it is usually found that the edges of the grooves leave slight ridges across the face of the wheel; these latter may mar the surface finish of the product.

Accuracy in the spacing of the thread grooves is essential, so also is consistency in size of all groove diameters. The periphery of the roller must be truly concentric. Crushing rollers are usually 3 in. to 4 in. diameter, 1 in. to 3 in. wide. Grooved rollers usually have 12 to 20 grit clearance grooves unequally spaced and cut spirally across the face width of the roller.

The grit clearance grooves usually have a depth at least twice that of the thread grooves. The angle or lead of the gashing depends upon the face-width of the wheel; the narrower the wheel the steeper should

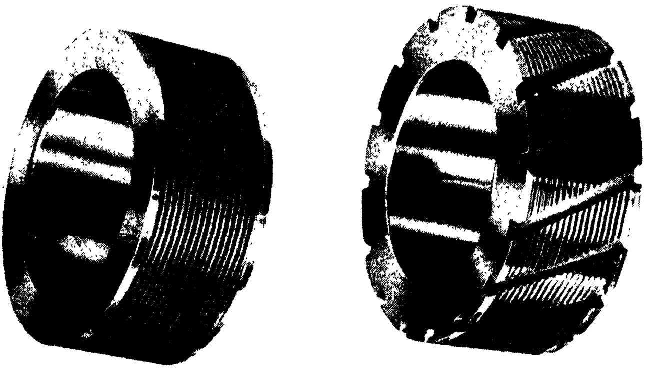


FIG. 60. GROOVED AND PLAIN CRUSHING ROLLERS
(*Courtesy of Coventry Gauge & Tool Co., Ltd.*)

be the helix. An angle of 30° is commonly used. Straight-cut gashing is not generally recommended. When a straight-cut groove comes round to the grinding wheel there is a slipping action between the wheel and the crusher. The slipping action tends to chatter the face of the wheel and may result in faulty thread forming.

Roller with Annular Thread Grooves and Ribs. When this type of roller is in use its only movement is rotary.

Roller with Helical Thread Grooves and Ribs. When this type of roller is in use its movement is both rotary and axial. The roller is made a sliding fit on a mandrel or arbor and, when fed into the periphery of the grinding wheel, is rotated and at the same time allowed to move axially. The authors prefer to use a roller with annular thread grooves.

THE CRUSHING OPERATION. It is a necessary preliminary to see that the grinding wheel is trued to run evenly and that it is tested and adjusted for balance. The truing operation consists of traversing a diamond tool across the face of the wheel. Then, the grinding wheel being stationary, the crusher roller is brought gently into contact with it so that when the wheel is rotated the roller will rotate also. The wheel is rotated either by a low-speed power drive (say 300 to 500

s.f.p.m.) or by hand. The advance of the roller or the wheel is by hand or power feed* and it is essential that this advance be sustained and regular—not spasmodic and irregular. The roller is fed, or rather "forced," into the grinding wheel. The amount by which the roller is forced into the wheel depends, of course, upon the condition of the roller and the resistance offered by the wheel. As a general rule it is recommended that the feed be equal to 0·001 in. per revolution of the wheel. The total amount of "feed" of the roller is, of course, equal to the depth of thread. This depth having been reached, the rotation of the wheel should be continued for a few turns to ensure a smooth surface.

Some operators, when commencing to form a grinding wheel, use a diamond tool to rough-out the grooves, finishing to form with a crushing roller. This, of course, is only practicable when dealing with rather coarse threads.

Experience shows that if a wheel is repeatedly crushed its face becomes loaded and glazed. It is then advisable to dress away the face of the wheel so as to remove the highly compressed loaded "skin." The wheel is then again crushed in the usual manner.

Use of Coolant. In the process of crushing it is essential to direct an ample flow of coolant on both the wheel and the crusher. It is not sufficient simply to flood the wheel and roller, the coolant must be applied so that it tends to force itself between the wheel and the roller. A little thought will demonstrate how essential it is that the coolant be properly filtered.

FORMING RIBS ON ROLLERS. As mentioned previously, the ribs on the crushing rollers are produced on thread-grinding machines using diamond-dressed wheels. Separate grinding of each annular groove is necessary when using a single-rib wheel. However, the whole face-width of the roller can be ground at the same time if a multi-rib wheel is employed, provided that the face width of the roller is less than that of the wheel. When the width of the roller is greater than that of the wheel—and this is often the case—two- or three-stage grinding is necessary.

STEPPED CRUSHING ROLLERS. Where a workpart has two thread diameters, the threads having the same pitch and lead, a suitable stepped crushing roller may be used to form the threads on the wheel. If correctly made, the crushing roller enables the wheel to grind the two thread diameters without entailing two separate feeds of the wheel into the workpart.

Fig. 61 shows how a plain-ground stepped crushing roller can be used to form the grinding wheel, so enabling four differently sized diameters to be ground on the unthreaded workpart at one setting of the machine. Note that in this illustration the workpart is ground with "plain" diameters—the blank being ground by the plunge-cut

* When the roller is mounted between the centres, the wheel is fed into the roller. In that case the advance of the wheel is by hand, or power-feed, and the wheel is fed into the roller.

method, i.e. the blank is given rotary motion only. The difference in size of the crusher diameters is, of course, the same as the difference in size of the diameters ground on the workpart.

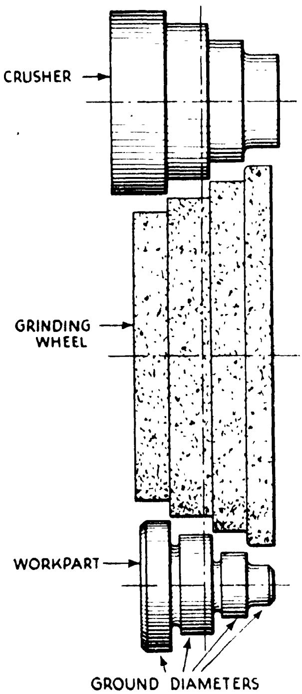


FIG. 61. STEPPED CRUSHER
Wheel Crushed to Grind Four Plain Diameters.

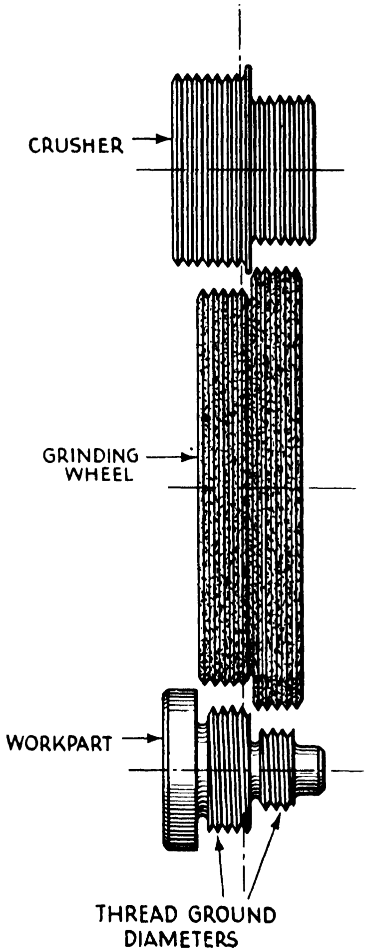


FIG. 62. STEPPED CRUSHER
Wheel Crushed to Grind Two Thread Diameters.

Fig. 62 shows the subsequent operation of thread grinding two of the four diameters on the workpart shown in Fig. 61. The stepped thread-grinding wheel is crushed with a stepped thread-ground crushing roller. This enables both diameters of thread to be ground at one setting of the machine.

FURTHER NOTES ON CRUSHING ROLLERS. Crushing rollers can be readily used for grinding tapered threads, incidentally also for

grinding workparts with both parallel and tapered portions. An example is shown in Fig. 63.

In some special applications the crushing method is employed for grinding workparts with both threaded and plain diameters.

When a small number of non-standard threads are to be ground it is usually found more economical to use a crushing roller than it is to use special-profile cams in conjunction with diamond tools. The special roller can be made in a lathe and ground on a universal grinding machine after heat treatment.

If the threads are of worm form, or have truncated crests, the limitations of the usual diamond form-dressing mechanisms make it necessary that the crest diameters be ground in an operation distinct from that

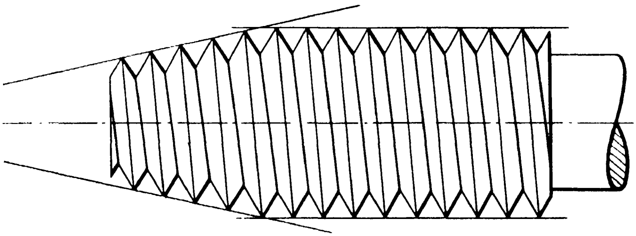


FIG. 63. WORKPART WITH TAPERED AND PARALLEL THREAD PORTIONS GROUND BY CRUSHED WHEEL

of grinding the thread. By using a "full form" crushing roller it is possible to form the wheel so that the "crest diameters" of the workpart can be "topped" at the same time as the thread itself is ground.

Crushing rollers are used to form the peripheries of grinding wheels used on *centreless grinding machines.* On these machines the diamond wheel-truing and dressing can be done before the crusher is used. The diamond is also used to form the chamfer or "throat" at the entrance edge of the wheel after the threads have been crushed. The reason for this chamfering is two-fold. Firstly, it enables the workpart to be ground on the outside diameter before threading begins; secondly, it enables the threads to be formed gradually so that the metal removal is distributed across the face of the wheel. The fully-formed grooves on the wheel remain to complete the thread form of the workpart as it leaves the grinding wheel. To form the wheel on this type of machine with a series of accurately spaced thread grooves and ridges by an alternative means would involve the provision of elaborate cams, styluses, and diamond tools.

The crushing method is speedy and cheap in terms of production obtained. Successful crushing of any kind pre-supposes that the wheel is of such design and quality that it can withstand the severe crushing action; furthermore, that it will retain the required form for a reasonable time.

Initial crushing on a new wheel is the most severe crushing operation and the thread form so obtained is often found to be short-lived. Subsequent re-crushing, however, in which only a few thousandths of

an inch are removed from the wheel, with accompanying reduced crushing pressure, leads to a thread form which is sustained considerably longer.

The Landis Tool Co. claim that production runs of about 14,000 ground threads, or more, are obtainable on their centreless thread grinders using a re-crushed wheel, before the wheel requires a renewal of its thread form. The Landis machines have a motor-driven crusher attachment, the crushers having a series of parallel ("annular") grooves. Their times for crushing have been given as: (1) about 1 minute for the removal of approximately 0·001 in. from the radius of the grinding wheel, (2) total time for entire re-crushing of a wheel about 10 to 12 minutes.

SPECIAL APPLICATIONS OF CRUSHING ROLLERS. Notable among the many special applications of thread-ground crushing rollers are: (1) The use of crushing rollers to form a series of thread grooves on the grinding wheels of plain cylindrical grinding machines to facilitate the production of workparts with annular grooves, e.g. circular type thread-chasing tools, duplicate crushing rollers, etc. The work is given rotary motion only. (2) Thread-ground crushing rollers are used to form the wheels on surface-grinding machines to facilitate the production of flat thread-rolling dies. In some cases the dies are roughed-out by milling with a multi-rib cutter; the grinding then being carried out after heat treatment of the dies.

Crushing rollers which have no threads ground on their outer surfaces are widely used in the production of form tools, rolls, gauges, and quantity production of workparts.

WHEEL FORMING BY CRUSHING. The crushing method of forming the peripheries of grinding wheels with one or more ribs is becoming more widely used. There are certain restrictions to its use for very accurate work, such as gauges and precision tools, yet its adoption for the majority of jobs of a commercial type has much to commend it. One feature, generally accepted as favourable in comparison with the diamond methods of wheel forming, is the cost reduction. It must, however, be pointed out that a comparison of the two methods cannot usefully be made without due consideration of the circumstances peculiar to a given job. For instance, one argument against the crushing method is that such heavy loads are introduced as result in a shortened life of the grinding-wheel spindle and bearings. From the point of view of time taken to form a wheel for grinding the crushing method has a slight advantage. Nevertheless, both methods call for equal care at all stages if satisfactory results are to be achieved.

The wheel must first be trued and balanced before the crushing method is employed. Wheel truing is dealt with in Chapter VIII. Wheel balancing is explained in Chapter IV.

Three Methods of Crushing. The three methods of crushing in general use are:

(1) Axes of wheel, crusher, and workpart in the same plane (Fig. 64).

(2) Axis of wheel tilted to common axes of crusher and workpart (Fig. 65).

(3) Common axes of wheel and crusher tilted to axis of workpart (Fig. 66).

The selection of one of these methods for any given job depends largely upon the degree of accuracy required.

The first method is illustrated in Fig. 64, which shows the axes of

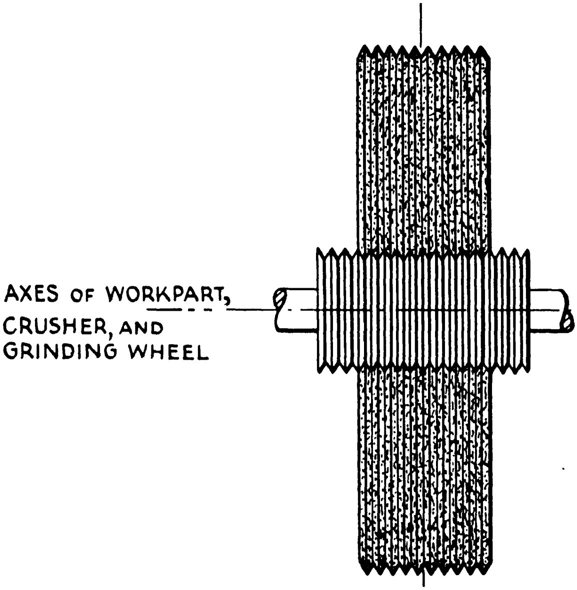


FIG. 64. AXES OF WHEEL, CRUSHER, AND WORKPART IN SAME PLANE

the grinding wheel, the crushing roller, and the workpart all in the same plane. This method is used for grinding annular grooves, an example of which is shown in Fig. 28. Note that with this method the form of the crusher on an axial plane is the same as those on the axial planes of both the grinding wheel and the workpart.

This method is frequently employed for grinding threads having small helix angles, but, due to the inherent helical interference between the helical grooves on the workpart and the annular grooves on the grinding wheel, it follows that errors in the form of thread on the workpart are unavoidable. However, on many jobs not requiring a high degree of accuracy this method is widely used. Generally, it will be found suitable for grinding workparts to commercial tolerances provided that the helix angle does not exceed about 2°. In some cases the wheel is set in the same plane as both the workpart and the crusher and then tilted to the helix angle after the crushing operation.

In the second method the grinding wheel is tilted so that its axis is inclined to the plane containing the axes of the crusher and the workpart. Due to the intersection of the axes a skidding action and a tendency to shear the thread ribs on the wheel results in a rapid wearing away of the form on the crusher. The skidding action referred to increases with increase in helix angle. Both the crusher and the

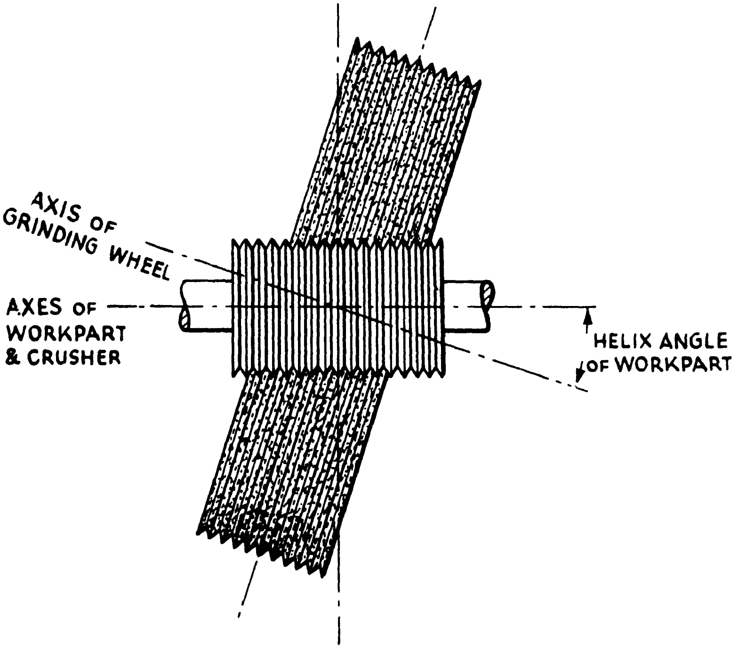


FIG. 65. AXIS OF WHEEL TILTED TO COMMON AXES OF CRUSHER AND WORKPART

wheel have a shorter serviceable life than would be the case if their axes were in the same plane. One good feature of this method is that the axial form of the product is theoretically the same as that of the crusher. Under average working conditions this method is suitable for grinding threads having helix angles not exceeding 2°, but, here again, the deciding factor is the degree of accuracy required.

In the third method the axes of the wheel and the crusher lie in the same plane, but are tilted normal to the helix of the thread to be ground. Fig. 66 shows that the axial form of the wheel and the crusher corresponds to the form on a normal-to-helix plane of the workpart. Therefore, if a high degree of accuracy were required it would be necessary to modify the form of thread on the crusher. The modification would necessitate making the axial form of the crusher identical with the normal form required on the workpart. In addition, a separate crusher would be required for each different helix angle. However, one crushing roller could be used for a number of helices provided that the difference

between the axial form of the crusher, and the normal form of the product, is within prescribed limits of inaccuracy. In many cases, dealing with mass-production to commercial tolerances, this difference can be ignored. The difference between axial and normal forms is clearly shown in Fig. 67.

EXTENDING SERVICEABLE LIFE OF A CRUSHING ROLLER. The serviceable life of a crushing roller is influenced by many factors.

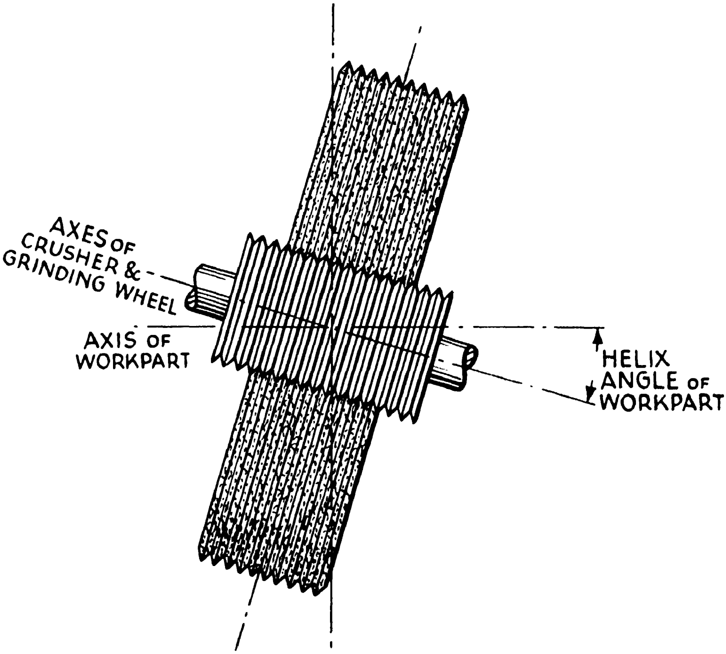


FIG. 66. COMMON AXES OF WHEEL AND CRUSHER TILTED TO AXIS OF WORKPART

One of these is known as "application" and it is by no means the least in importance. In shops where incentive methods of payment are in operation one sometimes sees interesting examples of the so-called "application factor." The following hypothetical case illustrates this matter.

Imagine two operators being given exactly similar thread-grinding jobs; in both cases for the second time. Both operators will have a good idea of the number of workparts that can be ground for each crushing of the wheel. Assume this number to be sixty. Suppose operator A is given one hundred workparts and operator B one thousand. In both cases particular care is taken in the initial crushing operations and each operator produces sixty workparts before commencing to re-crush the wheel. A re-crushes his wheel in less than half the time taken by operator B, this enabling him to complete his hundred workparts in less than the time allowed. However, his saving in

production time, while pleasing in itself, is robbed of its glamour when it is found that his roller is damaged beyond hope of further usefulness until re-ground. Meanwhile, operator B, continuing his policy of spending a reasonable time on successive crushing operations, may well succeed in completing his job in less than the time allowed, as well as maintaining his crusher in serviceable condition.

The life of a crushing roller is lengthened if the number of ribs on

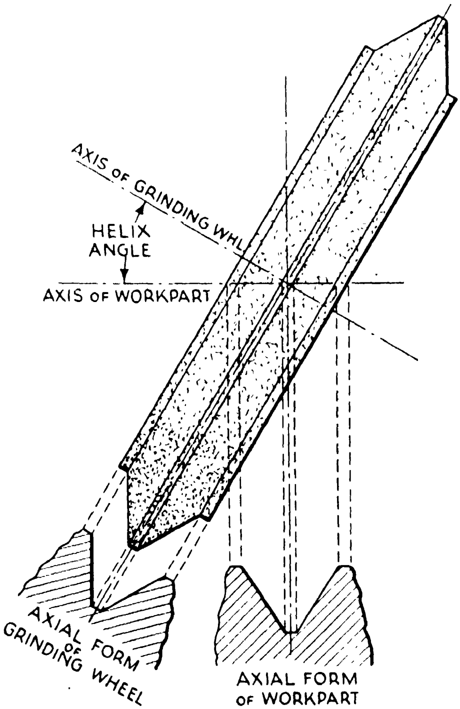


FIG. 67. AXIAL AND NORMAL FORMS OF THREAD

the wheel is restricted to the minimum for a given job. The part of the wheel not actually used for grinding should be cleared away.

It is good practice to make the crushing roller at least twice the width of the grinding wheel. This enables one half of the crusher to be used for "rough forming" and the other half for "finish forming" the wheel. By adopting this practice it is possible, in most instances, to re-grind the crusher by using the previously crushed wheel to grind a few thousandths of an inch from the diameter of the roller.

CRUSHING DEEP FORMS. When crushing deep forms, such as coarse-pitch threads, it is advisable to rough-out the grooves with a diamond tool. Where there is no provision for diamond-forming the wheel the following method may be employed.

A steel bar of about 5 in. length and 1 in. cross-section is drilled

with a hole perpendicular to its long axis and approximately in the centre of the bar. The diameter of the hole is drilled so as to enable the shank of a vee-edge diamond to be held within it. A second hole is drilled and tapped at right angles to the first, so that a grub screw can be inserted to secure the diamond tool. The bar is then placed between the centres of the machine. Having set the machine for the lead of the thread to be ground, the worktable is traversed so that the diamond is near one edge of the wheel. The wheel is then fed into the diamond to an extent slightly less than the depth of thread to be ground. The first groove being thus rough-formed, the wheel is withdrawn from the diamond. The worktable is moved an amount equal to the lead of the thread and the wheel again fed into the diamond to form the second groove. The process is repeated until the desired number of grooves are formed on the wheel. This stage having been reached the crushing roller can be employed in the usual manner, care being taken to match up the ribs of the crusher with the grooves in the wheel.

CHAPTER X

CHANGE WHEELS AND CHANGE-WHEEL CALCULATIONS

WHEN different pitches are required it is necessary to employ change wheels.

HOW DIFFERENT PITCHES ARE OBTAINED ON WORKPARTS. The rotation of the *work-driving shaft* is transmitted to the *lead screw* by a set of toothed spur wheels called *change wheels*. (See Fig. 68.) The lead screw winds through the nut attached to the main structure of the machine and is thus caused to traverse in an axial direction.

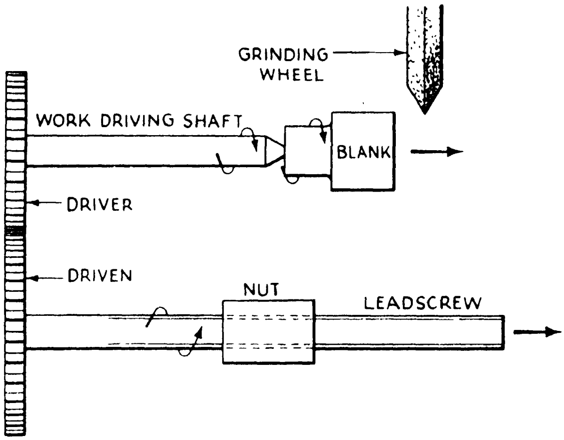


FIG. 68. DIAGRAM OF CHANGE WHEELS TRANSMITTING ROTATION AND TRAVERSE

The length of axial traverse is determined by the number of revolutions and the lead of the thread on the lead screw. The lead screw will, of course, traverse a distance equal to its lead for each complete revolution it makes.

The sliding table, carrying the headstock and tailstock units, is attached to the lead screw. Thus the workpart receives rotary motion from the work-driving shaft and moves axially in unison with the lead screw. The thread is produced by traversing the rotating workpart across the face of the grinding wheel. *The ratio of the rate of rotation to the rate of traverse controls the pitch of the thread ground on the workpart.* When the toothed wheel on the work-driving shaft has the same number of teeth as the wheel on the lead screw the latter will rotate and traverse at the same speed as the workpart. The lead of the ground thread will then be the same as the lead of the thread on the lead screw. To obtain any other lead it becomes necessary to change the lead screw. This is done in some cases. (See Fig. 69.) An alternative

method is to use a suitable set of toothed wheels. In most cases it is more economical to carry a stock of toothed wheels than a stock of lead screws; hence the term "change wheels."

CLASSIFICATION OF CHANGE WHEELS. The wheel on the work-driving shaft drives the wheel on the lead screw and is therefore called the *driver*. The wheel on the lead screw is called the *driven*.

In Figs. 68 and 70 the set of change wheels consist of a pair, i.e. one driver and one driven. By interposing a third wheel between the driver and driven we obtain a *single* or *open train*. (See Fig. 71.)

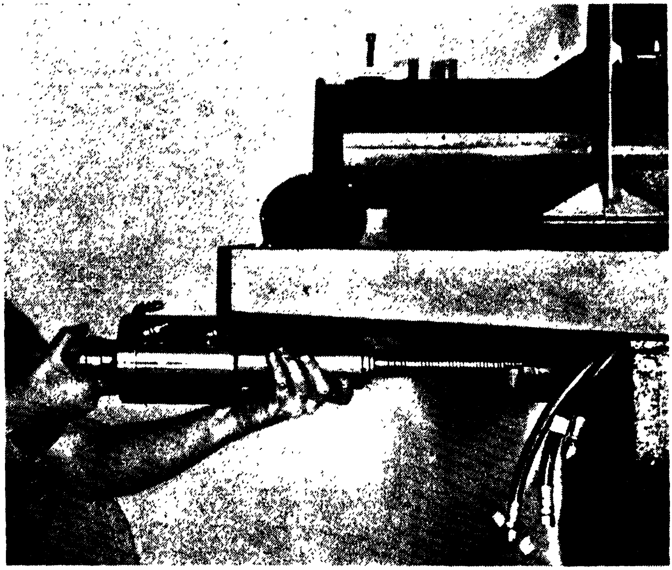


FIG. 69. INSTALLING LEAD SCREW ON EX-CELL-O THREAD-GRINDING MACHINE (STYLE 35)
(*Courtesy of Ex-Cell-O Corporation*)

This third wheel is called the *idler*—its function being transmission of power from the driver to the driven. The idler wheel is mounted on a stud which can be positioned in a slotted casting called a *quadrant* to enable correct meshing of the wheels. The quadrant is free to rotate about the end of the lead screw and may be locked in position by means of locking screws. (See Fig. 72, which shows a compound train.)

It is not always practicable to use an open train of change wheels and so use is made of a *compound train*. A compound train consists of four wheels, two of which are called *intermediate wheels*. (See Fig. 73.) Both intermediate wheels are mounted on the quadrant stud and are keyed together to ensure that they rotate at the same speed. The wheel on the work-driving shaft engages one of the intermediate

wheels called the *first driven*. The other intermediate wheel, called the *second driver*, engages the wheel on the lead screw. Thus in a compound train the first driver on the work-driving shaft engages the first driven

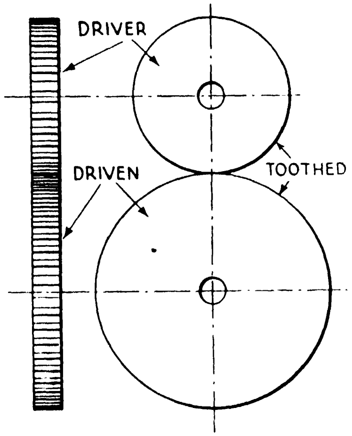


FIG. 70. PAIR OF CHANGE WHEELS

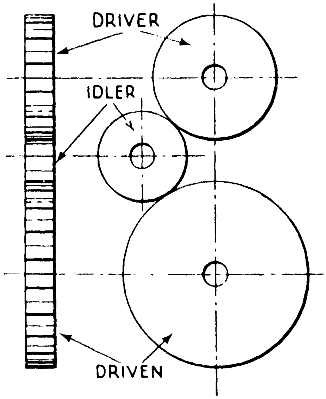


FIG. 71. SINGLE TRAIN

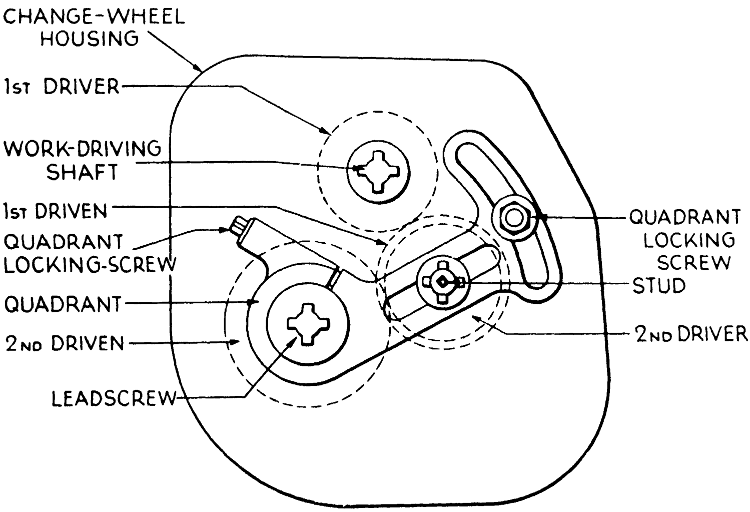


FIG. 72. ASSEMBLY OF CHANGE WHEELS COMPRISING AN OPEN TRAIN

mounted on the quadrant stud. The second driver, also mounted on the quadrant stud and keyed to the first driven, engages the fourth wheel, i.e. the second driven mounted on the lead screw. See Figs. 73 and 74.

THE CHOICE OF WHEELS. Generally speaking, the set of change wheels supplied with the thread-grinding machine include wheels

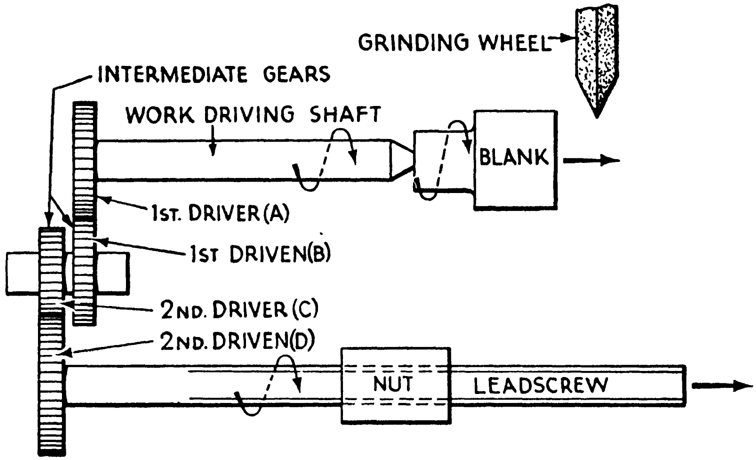


FIG. 73. DIAGRAM OF TRANSMISSION ARRANGEMENT USING A COMPOUND TRAIN

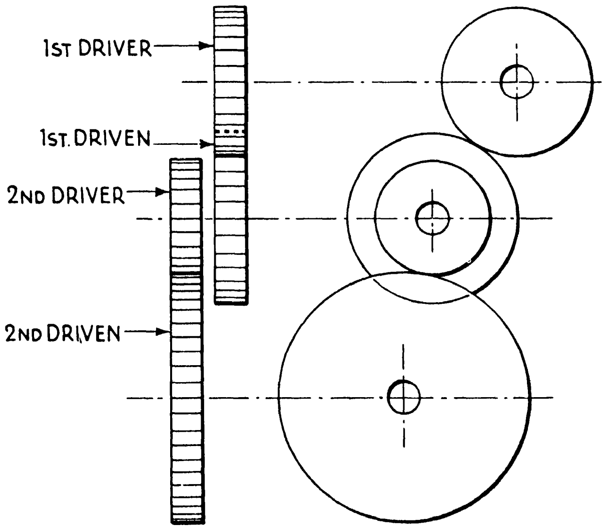


FIG. 74. COMPOUND TRAIN OF CHANGE WHEELS

ranging from about 24 to 96 teeth. In addition, a 127-toothed wheel is included for grinding metric pitches and, in some cases, a wheel having 113 teeth for grinding diametral pitch hobs and worms. The

sets of wheels vary with the make and type of machine, but in all cases the arrangement and calculation of the wheels is the same.

OBTAINING THE RATIO. Reverting to Fig. 68, it is clear that when the driver and driven gears have the same number of teeth the lead of thread ground on the workpart will be the same as the thread on the lead screw. Thus the following rules may be employed for finding the ratio.

RULE (1)

$$\textbf{Ratio} = \frac{\textbf{t.p.i. of lead screw}}{\textbf{t.p.i. to be ground}} = \frac{\textbf{No. of teeth in drivers}}{\textbf{No. of teeth in driven}}$$

RULE (2)

$$\textbf{Ratio} = \frac{\textbf{lead of thread to be ground}}{\textbf{lead of thread on leadscrew}} = \frac{\textbf{drivers}}{\textbf{driven}}$$

EXAMPLE 1. FIG. 68.

Assuming the lead of the thread on the lead screw is 0·1 in. and both driver and driven have the same number of teeth, then the lead of the ground thread will be 0·1 in.

By using a driver of, say, 60 teeth and a driven of, say, 40 teeth the ratio becomes 60/40. In this case the lead of the ground thread will be 60/40 × 0·1 in., i.e. 0·15 in.

By using the 40-toothed wheel as the driver, and the 60-toothed wheel as the driven, the ratio becomes 40/60. In this case the lead of the ground thread will be 40/60 × 0·1 in., i.e. 0·0666 in.

Before dealing with the subject of change-wheel calculations it should be pointed out that on some makes of machines the ratio is not based directly on the t.p.i. of the lead screw and the t.p.i. to be ground. Additional speed-change mechanisms are included in some cases and, of course, these determine the ratio. However, the ratio is usually shown on the change-wheel housing and in the handbook of operating instructions. Once having determined the ratio it is used in calculations as explained in ensuing paragraphs.

Change-wheel Calculations. There are restrictions on the employment of a pair of change wheels, hence the wide use of compound trains. No matter how many wheels comprise the train, rules (1) and (2) apply.

EXAMPLE 2. RULE (1)

6 t.p.i. on lead screw; 24 t.p.i. to be ground. Ratio = 6/24.

The numerator (6) denotes the number of teeth in the drivers. The denominator (24) denotes the number of teeth in the driven. Of course, it is impracticable to use two wheels having a product of only six teeth. Therefore, we multiply both numerator and denominator by some number to enable suitable wheels to be chosen.

It is convenient to describe the change wheels as follows—

First driver = A; First driven = B
Second driver = C; Second driven = D

This is the method usually followed in the handbooks and charts issued by machine manufacturers.

Employing Rule 1 we have the following—

$$\frac{6}{24} = \frac{\text{drivers}}{\text{driven}} = \frac{A \times C}{B \times D}$$

We can simplify the matter by factorizing both numerator and denominator of the ratio fraction, thus

$$\frac{6}{24} = \frac{3 \times 2}{6 \times 4} = \frac{A \times C}{B \times D}$$

We cannot employ wheels having 2, 3, 4, or 6 teeth, so we have to increase these numbers in the fraction, *without altering its value.* To do this we can multiply both the numerator and the denominator *by the same number.* Thus, if we multiply each term by ten, it is equivalent to multiplying both numerator and denominator by one-hundred. This would give

$$\frac{A \times C}{B \times D} = \frac{30 \times 20}{60 \times 40}$$

It is not usual to find a twenty-toothed wheel provided in the set, whereas a forty-toothed wheel is generally available. We can, therefore, multiply 20 by 2, and this entails multiplying one of the factors in the denominator by 2 also.

Thus $$\frac{A \times C}{B \times D} = \frac{30 \times 40}{60 \times 80}$$

Therefore we may use a first driver (A) having 30 teeth, a first driven (B) having 60 teeth, a second driver (C) having 40 teeth, and a second driven (D) having 80 teeth.

EXAMPLE 3. RULE (1)

Fractional pitch thread. 8 t.p.i. on lead screw; $4\frac{1}{2}$ t.p.i. to be ground.

$$\text{Ratio} = \frac{8}{4\frac{1}{2}} = \frac{16}{9} = \frac{A \times C}{B \times D}$$

Factorizing numerator and denominator, as in the previous example, we have $\frac{A \times C}{B \times D} = \frac{4 \times 4}{3 \times 3}$, a more convenient statement of the ratio.

We can next multiply both numerator and denominator by 10, so obtaining

$$\frac{A \times C}{B \times D} = \frac{40 \times 4}{30 \times 3}$$

We could, of course, repeat this multiplication in our endeavour to replace the numbers 4 and 3 by others more convenient, but might find that two 40-toothed wheels and two 30-toothed wheels are not available. We can, however, multiply both numbers by some other number, e.g. 12. Multiplying top and bottom by 12 we have

$$\frac{A \times C}{B \times D} = \frac{40 \times 48}{30 \times 36}$$

The compound train would then be—

First driver (A) . . 40 teeth; First driven (B) . . 30 teeth;
Second driver (C) . . 48 teeth; Second driven (D) . . 36 teeth.

EXAMPLE 4. RULE (2)

Lead of ground thread 0·28 in. Lead screw has 0·1 in. lead.

$$\text{Ratio} = \frac{0{\cdot}28}{0{\cdot}1} = \frac{28}{10} = \frac{A \times C}{B \times D}$$

Factorizing and multiplying as in the previous example, we have

$$\frac{7 \times 4}{5 \times 2} = \frac{70 \times 4}{50 \times 2} = \frac{70 \times 40}{50 \times 20} = \frac{70 \times 80}{50 \times 40}$$

Drivers: 70 and 80. Driven: 50 and 40.

Grinding Metric Pitches. A 127-toothed wheel is included in a standard set of change wheels to enable metric pitches to be ground. The following formula can be used to calculate the numbers of teeth in drivers and driven, *using an English pitch lead screw.*

$$\frac{A \times C}{B \times D} = \frac{5 \times \text{t.p.i. of lead screw} \times \text{metric pitch to be ground in mm}}{127}$$

EXAMPLE 5

Lead screw 10 t.p.i., required thread has 3 mm pitch.

$$\frac{A \times C}{B \times D} = \frac{5 \times 10 \times 3}{127} = \frac{50 \times 3}{127 \times 1} = \frac{50 \times 90}{127 \times 30}$$

Drivers: 50 and 90; Driven: 127 and 30.

Using a Metric Lead Screw. When a *metric lead screw* is used we employ the following formula to obtain the wheels for grinding threads with English pitches.

$$\frac{A \times C}{B \times D} = \frac{127}{\text{t.p.i. to be ground} \times \text{mm pitch of lead screw} \times 5}$$

EXAMPLE 6

Lead screw 4 mm pitch, required thread has 7 t.p.i.

$$\frac{A \times C}{B \times D} = \frac{127}{7 \times 4 \times 5} = \frac{127 \times 1}{28 \times 5} = \frac{127 \times 2}{56 \times 5} = \frac{127 \times 32}{56 \times 80}$$

Drivers: 127 and 32; Driven: 56 and 80.

CHANGE WHEELS FOR MORE DIFFICULT RATIOS. In previous examples we have dealt with comparatively simple ratios, all numbers employed, apart from 127, being capable of factorization at a glance. When dealing with more difficult ratios, however, it is often necessary to employ the method of *continued fractions*. In some cases it is found impossible to choose four wheels from a standard set to obtain the exact ratio. This may render it necessary to cut a special wheel having the desired number of teeth. Adopting a more optimistic strain, however, we should add that such a procedure should rarely be necessary. It is fallacious to work to a degree of exactitude in calculations far in advance of the degree of accuracy likely to be obtained with available equipment. Nevertheless it is well to err on the safe side in the calculations—bearing in mind the accuracy of the machine and the degree of precision required in the product. Let us commence with a very simple example.

EXAMPLE 7

Lead of required ground thread is 0·0321 in., lead screw has a lead of 0·1 in.

First find the ratio, thus

$$\frac{\text{Lead to be ground}}{\text{Lead of lead screw}} = \frac{\text{drivers}}{\text{driven}}$$

Then, Ratio $= \dfrac{0{\cdot}0321}{0{\cdot}1} = \dfrac{321}{1000}$. The next step is to convert this ratio into *a continued fraction.*

Divide the numerator (321) into the denominator (1000) and so obtain the first quotient (3). The first remainder (37) is then divided into the first divisor (i.e. the numerator 321). This gives the second quotient (8) and leaves the second remainder (25), which is divided into the previous divisor (37). This process is continued, i.e. remainders are divided into the previous divisors until there is no remainder. In this way we obtain an important series of quotients.

321)1000(3 (1st quotient)
963
*37)321(8 (2nd quotient)
296
25)37(1 (3rd quotient)
25
12)25(2 (4th quotient)
24
1)12(12 (final quotient)
12
. .

* This is the first remainder and second divisor.

Successive quotients are 3, 8, 1, 2, 12.

Write the fraction $\frac{0}{1}$ (do this always as a first step). Then write down the fraction "one divided by the first quotient," i.e. in this case, $\frac{1}{3}$.

Next multiply both numerator and denominator of the last fraction ($\frac{1}{3}$ in this case) by the next quotient (8) and add the results to the numerator and denominator of the preceding fraction ($\frac{0}{1}$). Thus $1 \times 8 = 8$; $3 \times 8 = 24$; $8 + 0 = 8$; $24 + 1 = 25$. In this way we obtain $\frac{8}{25}$ (the third fraction in the row below).

Then multiply $\frac{8}{25}$ by the next quotient (1) and add numerator and denominator of preceding fraction ($\frac{1}{3}$), thus

$$\frac{8 \times 1 + 1}{25 \times 1 + 3} = \frac{9}{28}$$

Then multiply $\frac{9}{28}$ by the next quotient (2) and add numerator and denominator of preceding fraction ($\frac{8}{25}$), thus

$$\frac{9 \times 2 + 8}{28 \times 2 + 25} = \frac{26}{81}$$

Then multiply $\frac{26}{81}$ by the next quotient (12) and add numerator and denominator of preceding fraction ($\frac{9}{28}$), thus

$$\frac{26 \times 12 + 9}{81 \times 12 + 28} = \frac{321}{1000}$$

Here we have the range of fractions (or *convergents*) obtained—

$$\frac{0}{1},\ \frac{1}{3},\ \frac{8}{25},\ \frac{9}{28},\ \frac{26}{81},\ \frac{321}{1000}$$

The final fraction is equal to the original ratio, and this checks the arithmetic.

All these fractions are approximately equal to the given ratio, those at the right-hand end of the row being the most nearly equal to it.

Errors in Successive Fractions :

1st Fraction. $\frac{1}{3} = 0{\cdot}333333$. Error $= + 0{\cdot}012333$

2nd Fraction, $\frac{8}{25} = 0{\cdot}320000$. Error $= -\ 0{\cdot}001000$
3rd Fraction, $\frac{9}{28} = 0{\cdot}321429$. Error $= +\ 0{\cdot}000429$
4th Fraction, $\frac{26}{81} = 0{\cdot}320988$. Error $= -\ 0{\cdot}000012$

Assuming that the error in the 4th fraction is permissible we calculate the numbers of teeth in the usual manner, as follows:

$$\frac{26}{81} = \frac{13 \times 2}{9 \times 9} = \frac{52 \times 2}{36 \times 9} = \frac{52 \times 20}{36 \times 90} = \frac{52 \times 40}{72 \times 90}$$

Drivers: 52 and 40; Driven: 72 and 90.

Continued Fractions Explained More Generally.

$$\cfrac{1}{3 + \cfrac{1}{3 + \cfrac{1}{4}}}$$

Examine the form of this fraction. It is a typical *continued fraction*.

Its numerator is unity; its denominator is a whole number plus a fraction. The latter fraction also has unity for its numerator and a whole number plus a fraction for its denominator.

Continued fractions enable change-wheel calculations to be simplified because by using them we are enabled to find fractions expressed in smaller numbers, but having values approximately equal to the value of a given fraction expressed in large numbers. Especially is this useful when one or both of the large numbers in the given factors are *primes*, i.e. they cannot be factorized.

Consider the fraction $\frac{321}{1000}$. This occurs in Example 7. Actually, of course, its denominator and numerator are readily factorized, but as the numbers are comparatively large it will serve as a useful illustration. Our purpose is to find fractions with smaller numbers but which have values close to that of the given fraction. Suppose we "cancel" by 321, i.e. divide both numerator and denominator by 321. This will not change the value of the fraction but will present it in a different form. Thus we have,

$$\frac{1}{3\frac{37}{321}} \text{ or } \frac{1}{3 + \frac{37}{321}}$$ (a *continued fraction* which has exactly the same value as $\frac{321}{1000}$)

Suppose we discard $\frac{37}{321}$. We shall then be left with the fraction $\frac{1}{3}$, which is larger than $\frac{321}{1000}$ because we have reduced the denominator in the continued fraction. The advantage of the fraction $\frac{1}{3}$, compared with the fraction $\frac{321}{1000}$, is that it is less unwieldy. To compare the

various magnitudes of the fractions we can first find the L.C.M. of 1000 and 3. It is obviously 3000. Then we can express each in the following terms:

$$\frac{321}{1000} : \frac{1}{3} \qquad \text{(L.C.M. of 1000 and 3 = 3000)}$$

$$\frac{963 : 1000}{3000}$$

Thus $\frac{321}{1000} = \frac{963}{3000}$, whilst $\frac{1}{3} = \frac{1000}{3000}$. This is clearly a difference of $\frac{37}{3000}$: $\frac{1}{3}$ being the larger.

Similarly, we can convert $\frac{37}{321}$ into a continued fraction, thus obtaining

$$\cfrac{1}{3 + \cfrac{1}{8 + \cfrac{25}{37}}}$$

and continuing further in two stages,

$$\cfrac{1}{3 + \cfrac{1}{8 + \cfrac{1}{1 + \cfrac{12}{25}}}} \; ; \qquad \cfrac{1}{3 + \cfrac{1}{8 + \cfrac{1}{1 + \cfrac{1}{2 + \cfrac{1}{12}}}}}$$

so obtaining the continued fraction which is exactly equal to $\frac{321}{1000}$.

In the last continued fraction the denominators 3, 8, 1, and 2 are incomplete quotients, as they are the integral parts of successive quotients. The first expression in the continued fraction is $\frac{1}{3}$, which is a little larger than 0·321. If we take $\cfrac{1}{3 + \cfrac{1}{8}}$ we get $\frac{8}{25}$ as the next nearest fraction to 0·321.

To get still nearer, we can take in the next part of the continued fraction, and we have,

$$\cfrac{1}{3 + \cfrac{1}{8 + \cfrac{1}{1}}}$$

To simplify this, perform the operations step by step.

Thus $$8 + 1 = 9; \; 3 + \frac{1}{9} = \frac{28}{9}; \; \cfrac{1}{\frac{28}{9}} = \frac{9}{28}$$

Taking in the next part we get

$$\cfrac{1}{3+\cfrac{1}{8+\cfrac{1}{1+\cfrac{1}{2}}}} = \cfrac{1}{3+\cfrac{1}{8\frac{2}{3}}} = \cfrac{1}{3+\cfrac{3}{26}} = \frac{26}{81}$$

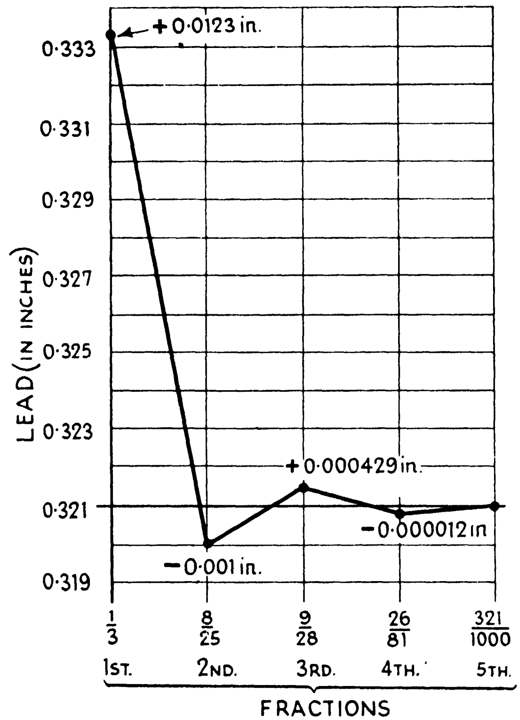


FIG. 75. GRAPH SHOWING ERRORS IN SUCCESSIVE CONVERGENT FRACTIONS

and if we simplify the whole fraction we get the original 0·321. Hence the approximations are

$$\frac{1}{3}\ ;\ \frac{8}{25}\ ;\ \frac{9}{28}\ ;\ \frac{26}{81}$$

It may be noted from these examples that

(1) Any convergent can be found at once from the two convergents immediately preceding it.

(2) Any convergent is more nearly equal to the continued fraction than any preceding convergent.

(3) The convergents are alternately less and greater than the continued fraction (see the graph in Fig. 75).

(4) Convergents are in their lowest terms and cannot be reduced further by cancelling.

Examples for Practice

(1) Given the fraction $\frac{591}{1888}$, convert it into a continued fraction and write down the first four convergents.

(2) Proceed similarly with $\frac{233}{522}$.

(3) Given a ratio of $\frac{0\cdot0623125}{0\cdot2}$, employ the method shown in Example 7 to find a series of convergents.

ANSWERS

(1) Four convergents: $\frac{1}{3}, \frac{5}{16}, \frac{36}{115}, \frac{185}{591}$.

(2) Four convergents: $\frac{1}{2}, \frac{4}{9}, \frac{25}{56}, \frac{104}{233}$.

(3) $\frac{0}{1}, \frac{1}{3}, \frac{4}{13}, \frac{5}{16}, \frac{19}{61}, \frac{43}{138}, \frac{62}{199}, \frac{291}{934}, \frac{353}{1133}, \frac{997}{3200}$.

When the Ratio is Greater than Unity. In Example 7 the ratio was less than unity. When the ratio is greater than unity a slightly different method is followed, as explained below.

EXAMPLE 8

Lead of required ground thread is 0·27397 in., lead screw has a lead of 0·1 in.

$$\text{Ratio} = \frac{\text{lead to be ground}}{\text{lead of lead screw}} = \frac{0\cdot27397}{0\cdot1} = \frac{2\cdot7397}{1}$$

The first step is to express the ratio as a value less than unity. This is done by finding the reciprocal of the ratio and using it as the numerator of the new ratio. Thus, reciprocal $= 1 \div 2\cdot7397 = 0\cdot365003$. Drivers and driven are then inverted.

$$\text{Hence} \quad \frac{\text{Driven } (B \times D)}{\text{Drivers } (A \times C)} = \frac{0\cdot365}{1} \text{ (taking ratio as } 0\cdot365)$$

Continued fractions are then found in the usual manner.

```
365)1000(2
     730
     ---
     270)365(1
         270
         ---
          95)270(2
             190
             ---
              80)95(1
                 80
                 --
                 15)80(5
                    75
                    --
                     5)15(3
                       15
                       --
                       ..
```

Successive quotients are: 2, 1, 2, 1, 5, 3. Using the method shown in Example 7 we arrive at the following convergent fractions.

(1) $\frac{0}{1}$

(2) $\frac{1}{2}$

(3) $\frac{1 \times 1 + 0}{2 \times 1 + 1} = \frac{1}{3}$

(4) $\frac{1 \times 2 + 1}{3 \times 2 + 2} = \frac{3}{8}$

(5) $\frac{3 \times 1 + 1}{8 \times 1 + 3} = \frac{4}{11}$

(6) $\frac{4 \times 5 + 3}{11 \times 5 + 8} = \frac{23}{63}$

(7) $\frac{23 \times 3 + 4}{63 \times 3 + 11} = \frac{73}{200}$

Errors in successive convergent fractions are as follows, when the value of the ratio is taken as 0·365003, although previous calculations have been simplified by taking it as 0·365.

1st Fraction,	$\frac{1}{2}$ = 0·500000.	Error =	+ 0·134997
2nd Fraction,	$\frac{1}{3}$ = 0·333333.	Error =	− 0·031670
3rd Fraction,	$\frac{3}{8}$ = 0·375000.	Error =	+ 0·009997
4th Fraction,	$\frac{4}{11}$ = 0·363636.	Error =	− 0·001364
5th Fraction,	$\frac{23}{63}$ = 0·365079.	Error =	+ 0·000076
6th Fraction,	$\frac{73}{200}$ = 0·365000.	Error =	0 (taking ratio as 0·365)

Assuming that the 5th fraction, $\frac{23}{63}$, is selected, the wheels are calculated thus

$$\frac{\text{Driven}}{\text{Drivers}} = \frac{B \times D}{A \times C} = \frac{23}{63} = \frac{23 \times 1}{9 \times 7} = \frac{46 \times 1}{18 \times 7} = \frac{46 \times 30}{54 \times 70}$$

Drivers: 54 and 70; Driven: 46 and 30.

Using the exact fraction, $\frac{73}{200}$, we could find the wheels thus,

$$\frac{73}{200} = \frac{73 \times 1}{25 \times 8} = \frac{73 \times 3}{75 \times 8} = \frac{73 \times 30}{75 \times 80}$$

Drivers: 75 and 80; Driven: 73 and 30.

Factorizing; Tests of Divisibility

(1) *Divisibility by* 2 *or* 5. A number is divisible by 2 (or by 5) if the last figure either is 0 or is itself divisible by 2 or 5.

(2) *Divisibility by* 3 *or* 9. A number is divisible by 3 or by 9 if the sum of the digits is so divisible.

(3) *Divisibility by* 11. A number is divisible by 11 when the difference between the sums of alternate digits is 0 or is divisible by 11.

EXAMPLE

$$\text{Ratio is } \frac{7128}{7623}$$

Adding alternate digits in numerator, commencing with the units digit, we get 8 + 1 = 9. Adding alternate digits in the numerator, commencing with the tens digit, we get 2 + 7 = 9. Hence 7128 is divisible by 11. Similarly 7623 is divisible by 11.

Hence $\frac{7128}{7623} = \frac{11 \times 648}{11 \times 693}$, or $\frac{648}{693}$, or $\frac{9 \times 72}{9 \times 77}$, or $\frac{72}{77}$

CHAPTER XI

GRINDING INTERNAL THREADS

THE high degree of accuracy, together with simplicity in operation associated with modern thread-grinding machines, enables internal threads to be ground as both toolroom and commercial operations. Different pitches are obtained by using different change wheels or suitable leadscrew-and-nut assemblies in the same manner as when grinding external threads.

The different methods of forming and form-dressing grinding wheels, described in Chapter VIII, are all applicable to internal thread grinding. In addition, all four methods of grinding dealt with in Chapter III are used, the method employed in most cases being *single-rib traverse grinding*. Crushing rollers are sometimes used for wheel-forming but are not generally recommended in connexion with internal grinding wheels.

TWO TYPES OF MACHINES. For grinding internal threads two types of machines are used. The type most widely used is referred to as a *universal* machine, this type of machine being adaptable for grinding both internal and external threads. See Fig. 7. For internal grinding a special spindle and drive assembly is mounted to the wheelhead which normally houses the external thread-grinding wheel.

The other type of machine is designed solely for grinding internal threads. A typical precision internal thread-grinding machine is shown in Fig. 10.

SIZE RANGE OF INTERNAL THREAD GRINDING. Thread pitches as fine as 40 t.p.i. and as coarse as 1 t.p.i. are ground on modern machines. Both single- and multi-start threads may be ground on diameters of less than ½ in. and as large as 18 in. The length of thread that can be ground depends, of course, on the capacity of the machine and physical dimensions of the workpart. In some cases the length of ground thread exceeds 15 in.

By using special equipment it is possible to grind relieved or "backed-off" internal threads such as are sometimes used on solid and adjustable types of thread dies.

WORK MOUNTING. The workpart to be ground is mounted in a chuck, on a faceplate, or jig attached to the headstock and work-driving spindle. When a number of similar parts are to be ground special work-holding devices may be employed, these being air-operated, magnetic, or worked by a drawbar action. It is essential in all cases that particular care be taken to ensure that workparts are rigidly held and are well balanced.

When grinding screw ring gauges, or similarly shaped workparts, it is recommended that they be clamped to a faceplate. A method usually employed when grinding a number of screw ring gauges is

first to grind the "blanks" as shown in Fig. 76. Note that the face of the gauge is ground to ensure that when mounted on the faceplate of the thread-grinding machine the gauge will have a good register face and that the axis of the thread will be square to the face of the gauge. The position of the grinding wheel when grinding the face of the gauge is shown in Fig. 76 (*a*). At the same setting, that is without moving the gauge, the centralizing diameter is ground as shown in Fig. 76 (*b*). The latter operation enables the thread-grinding operator to adjust the blank so that it is mounted concentrically on the faceplate of the thread-grinding machine.

Fig. 77 shows the set-up for centralizing the gauge on the faceplate.

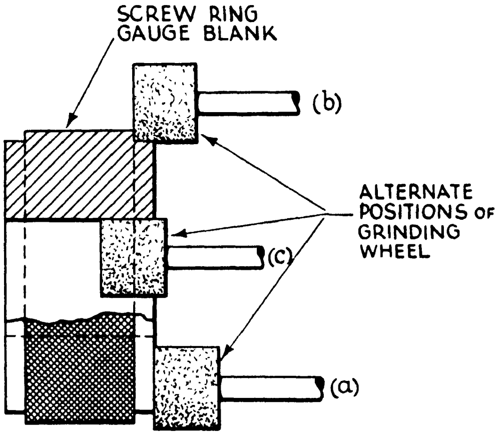


FIG. 76. PRELIMINARY STEPS IN GRINDING A SCREW RING GAUGE

Note that the gauge is clamped to the faceplate by means of a drawbar. By using an indicator or "clock" gauge the blank can be positioned centrally. The indicator arm is placed on the ground centralizing diameter, Fig. 78, and, by rotating the faceplate, the amount by which the gauge has to be moved to rotate concentrically is shown on the dial of the indicator.

The bore of the gauge is ground at the same setting as grinding the face and the centralizing diameter. See (*c*) in Fig. 76.

ACCURACY. The degree of accuracy that can be obtained depends to a large extent upon the proficiency of the machine operator. Under average conditions work can be produced within $\pm 0{\cdot}0002$ in. of prescribed diameter dimensions. Accuracy in pitch and lead is usually within 0·0002 in. per inch length of thread.

Test plugs and/or measuring instruments are used for checking the thread diameters. The use of test or "check" plugs is fully explained in *Notes on Screw Gauges* (H.M.S.O.). The pitch of thread can be checked on a pitch measuring machine. (See Fig. 95.) The form of the ground thread may be checked by taking a mould or "cast" of

the thread, and comparing it with a reference or standard form on an optical projector.

STOCK ALLOWANCE. The list of stock allowance recommendations on page 35 may be used when deciding the quantity of surplus material to be allowed for in internal thread grinding. It is generally recommended that threads with pitches coarser than 12 t.p.i. be pre-cut

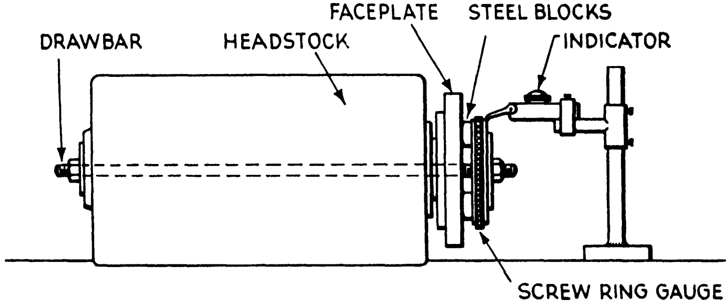


FIG. 77. SET-UP FOR CENTRALIZING WORK FOR GRINDING AN INTERNAL THREAD

by screw-cutting on a lathe, by tapping, or by thread-milling. Equipment is usually supplied for matching-up the roughed-out groove with the thread form on the grinding wheel.

WORK SPEED. The work speeds used are, to a large extent governed by the nature of the material and the depth of thread. However, most internal thread grinding is carried out at a work speed between 1 r.p.m. and 16 r.p.m. Pages 32 and 53 give further data on recommended work speeds.

DEPTH OF CUT. With the exception of threads coarser than 12 t.p.i., which are usually pre-cut, internal threads are ground from the solid blank. Initial cuts of 0·03 in. to 0·1 in. depth are not uncommon but most suitable depths are found by trial. Under average conditions final sizing cuts between 0·004 in. and 0·008 in. on diameter give best results. When dealing with work required to extremely close limits the finishing cuts may advantageously be of 0·001 in. depth or less.

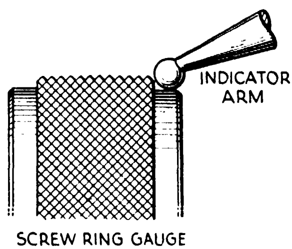


FIG. 78. USING AN INDICATOR WHEN SETTING UP THE BLANK

USE OF COOLANT. The importance of correct cooling cannot be overstressed. More difficulty in applying the coolant is met with when grinding the smaller diameters of internal threads as it is not always practicable to arrange for the coolant nozzle to enter the bore of the workpart. Auxiliary coolant supplies are often necessary. Best

results are obtained when coolant is applied through the bore of the headstock spindle. This supply can be augmented by arranging another supply of coolant to impinge upon the contact area of the wheel and workpart. Care should be taken to arrange the supply of coolant in such a manner that the particles of swarf and abrasive are washed *away* from the grinding wheel.

SELECTION AND MOUNTING OF QUILLS. The grinding wheel is

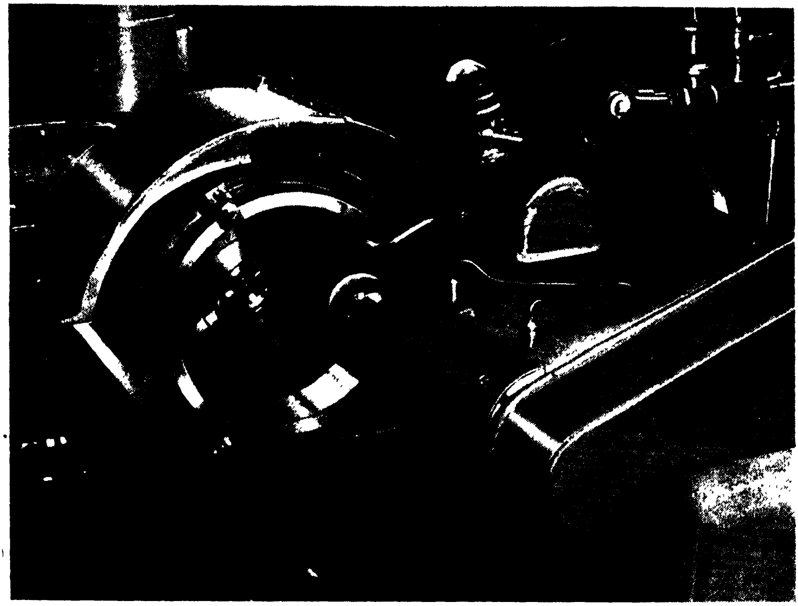


FIG. 79. INTERNAL THREAD-GRINDING ATTACHMENT FITTED TO A MATRIX GRINDING MACHINE
(The component shown is a Ring Gauge.)

mounted on the end of a *quill* or "spindle extension." The quill, in turn, is fitted to the internal grinding spindle, usually by inserting the tapered end of the quill into the tapered bore of the spindle. A threaded drawbar is used to secure quill and spindle and should be tightened to a degree sufficient only to seat the quill properly in the tapered bore. Both quill and spindle should be perfectly clean before being fitted together.

A cold quill must never be fitted to a warm spindle as expansion of the quill and contraction of the spindle will cause seizure. Allowing the quill to rest loosely in the spindle for a few minutes will help to equalize the temperatures.

A set of quills of different sizes is usually supplied as standard equipment. The selection of the most suitable quill depends on the nature of the work. The aim should be to select a quill that has most rigidity under actual working conditions. Thus, the quill should be

as short and as robust as it is possible to use. Long quills are used for grinding long lengths of thread or when the thread to be ground has a "facing," i.e. an "unthreaded diameter." The larger the quill diameter the slower should be the wheel speed.

INTERNAL GRINDING SPINDLES. Success in grinding internal threads can be obtained only when the grinding spindle is in first-class condition. Under heavy loads the spindle should operate with complete freedom from vibration. Most spindles are of ball-bearing type and are manufactured and assembled with extreme precision. Due to the extraordinary care required in the use and care of spindles it is generally recommended that they be returned periodically to the makers for service and overhaul.

The speed of the spindles is, in many cases, predetermined by the makers and different spindles are supplied for operating at prescribed speeds. In selecting a spindle the load-carrying capacity should be considered. Evidently a slower-running heavy spindle has a much greater load-carrying capacity than a faster-running lightweight spindle. The slower the spindle speed the heavier the cut that can be taken. The slower the spindle speed the larger may be the quill diameter. Rigidity of support governs efficiency of the grinding wheel.

INTERNAL HELIX ANGLE. Helix angles of internal threads are, of course, calculated in the same manner as for external threads. The table of helix angles on pages 187 to 193 will be found useful.

The greater the helix angle of the work the shorter becomes the length of thread that can be ground. This is due to interference caused by the tilting of the grinding wheel housing which brings the quill nearer to contact with the mouth of the work.

In setting up the machine it must be remembered that the helix angle of an internal thread is opposite to that of an external thread of the same hand. When dealing with quantity production of work-parts to commercial tolerances it is customary to leave the grinding wheel set at zero helix for threads not exceeding 3° helix angle.

GENERAL NOTES. Factors which govern success or failure in grinding internal threads are similar to those which apply to grinding external threads. Therefore, appropriate sections of this book should be referred to for particulars concerning selection and mounting of grinding wheels; coolants; forming and form-dressing; machine-setting operations, wheel and work speeds; diamond tools; etc.

CHAPTER XII

SURFACE FINISH

SHORTCOMINGS in the surface finish of thread-ground work may be grouped under the following five headings. In the ensuing notes the common causes of these inaccuracies are discussed and remedies suggested.

(*a*) Burning.
(*b*) Chatter.
(*c*) Dull finish.
(*d*) Scratched surface.
(*e*) Surface cracks.

(*a*) **BURNING OF THE WORKPIECE.** This is generally avoided by a copious supply of suitable coolant, the flow of which is correctly applied. The stream of coolant should impinge upon the point of the wheel where it contacts the work. Burning can generally be remedied by using a lighter feed, a slower wheel speed, or a higher work speed.

The coolant should be plentiful in supply and kept reasonably clean and cool. Obviously a stream of warm liquid has no useful cooling property. It has been found that burning results from grinding the work before the machine has had time to "warm up." Some users recommend that the machine be allowed to run for about a quarter of an hour at its operating speed before being used for an actual grinding operation.

If burning persists after attention has been paid to feed, speeds, and coolant, and correct selection of the wheel, the cause may be that the outer or peripheral surface of the wheel has become glazed. Re-truing of the wheel with perfectly sharp diamonds will, of course, overcome this fault. Dull diamonds produce dull cutting surfaces on the wheel. Burning of the work may indicate that the wheel is too hard and a wheel of coarser grain may advantageously be substituted for the wheel in use. As mentioned under the heading *Cutting Action* on page 51, the wheel speed may be altered to give a softer cutting action, or the work speed may be increased with good effect.

Remedies for burning are as follows—

Use softer wheel.
Reduce wheel speed.
Increase work speed.
Renew coolant.
Use less viscous coolant.
Decrease depth of cut.
Dress wheel with sharp diamonds.
Ensure that wheel is balanced.

(*b*) **CHATTER MARKS.** Chatter marks are attributable to so many causes that it is usually more troublesome to eliminate "chatter" than

any other surface blemish. However, it can be stated with confidence that the most frequent cause of chatter is the abrasive wheel being "out of balance." Evidently, therefore, the greatest care must be taken to see that the wheel is "in balance" before it is mounted on the spindle. Wheel balancing is discussed in Chapter IV. Glazing of the wheel causes chatter. See Fig. 80 (*a*).

Wheel washers tend to absorb vibration transmitted through the wheel spindle and omission of such washers may cause chatter. Worn thrust races in the wheel spindle assembly and/or excessive "play" in the work drive mechanism will cause chatter.

Improper seating of the headstock and tailstock units; loose or badly fitting centres; lack of rigidity in mounting and driving of the work; transmission gearing not being smooth and constantly positive in action; vibration in the machine due to electric motors not being attached securely; vibration due to unsuitable foundation or loose foundation bolts; work of irregular cross-section running out of balance; vee-pulley belt sheaves being out of alignment; "whip" in the belts; finishing cuts being too deep; inaccurate wheel-dressing; dulled diamonds; all have an influence in introducing chatter marks to the work surface.

The presence of chatter is readily disclosed by slowly rotating the work under a strong light. The many peripheral flat spots reflect back the light at many different angles. If the work surface is not chattered, no such flickering of the light will occur.

The trouble may be due to a part or parts of the machine being set into a state of vibration through having become loose. In very troublesome cases it pays to use some sort of oscillograph instrument to indicate the amount of vibration at different places on the machines and so, by disclosing the sources of vibration, enable it to be traced and rectified.

(*c*) **DULL FINISH.** This results from the work- and wheel-speeds being too slow, the consequence being that the material is rubbed or forced out of place instead of being cut away keenly. A glazed wheel has much the same effect, and attention should therefore be given to checking (1) the cutting edges of the diamonds, (2) the speed and feed used in the wheel form-dressing operation.

(*d*) **SCRATCHES ON THE WORK SURFACE.** These are generally traceable to the use of dirty coolant. Minute chips of abrasive and impurities suspended in the coolant are pumped through the supply system and become wedged between the wheel and the work, thus causing slight tearing and scratching of the thread surface. See Fig. 80 (*b*) and (*c*).

Frequent replacement of the coolant and regular cleaning of the filtration unit are essentials to obtaining a good finish.

(*e*) **SURFACE CRACKS.** Surface cracks tend to arise when the material being ground is very hard and brittle. Cracking is avoided by using a wheel as coarse in grain as possible, by ensuring that the wheel is

running in perfect balance, and by arranging a liberal and well-directed supply of coolant of greater "oiliness" and of rather higher viscosity than is normally used.

Excessive heating of the wheel and the work accentuates the formation of surface cracks and this may be avoided by taking very light cuts at a work-speed of about 10 surface feet per minute.

MIRROR FINISH. A mirror finish is obtained only after a careful selection of abrasive wheel, coolant-lubricant, speeds, feeds, and correct work mounting.

High wheel-speeds; low work-speeds; and light finishing cuts after efficient wheel dressing with sharp securely-held diamonds; plenty of cutting fluid—cleanly cool as a coolant and having great "oiliness" as a lubricant—and a wheel in perfect balance, are all factors which contribute towards obtaining a mirror-like surface finish.

POLISHING. This becomes a laborious operation only when the ground surface is inferior. Therefore any time given to obtaining a good smooth scratch-free grinding finish is amply repaid in the polishing operation.

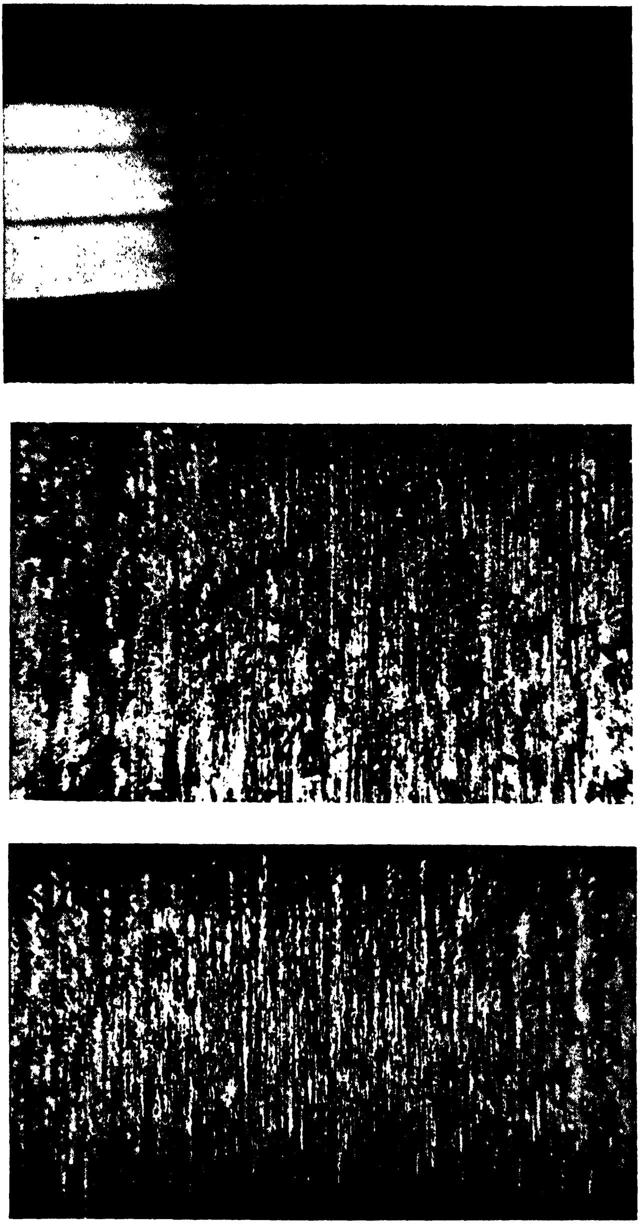
It should be noted that polishing is an entirely different operation from lapping and that it is not the aim in the polishing operation to remove any measurable amount of material from the work surface.

It is a well-established practice to polish, after grinding to size, by using a *Selvet* or similar cloth soaked in a mixture of thin lubricating oil, pure soap, and jewellers' rouge of commercial quality. This pasty mixture is applied fairly thickly, at first with the thread-part rotating at about 30 to 35 surface feet per minute, gradually applying pressure with the cloth wrapped around the work. The operation is finished by *dry polishing*—french chalk sometimes being used.

A number of proprietary compounds for polishing ground threads are marketed.

LAPPING. Lapping of male threads is seldom, if at all, necessary, provided that the thread has been correctly ground. On the other hand the lapping of female threads, as in screw-ring gauges, is practised widely. In fact it may well be claimed that modern thread-grinding practice has now reached such a high degree of excellence—with easily-attained accuracy to very close limits—that the lapping of male threads will become redundant. In the future it is probable that lapping will not be considered as one of the essential operations in the production of an accurate screw-plug gauge, but that its use will be restricted to the correction of such small errors of grinding as may arise.

On male threads the trouble of wheel-form breakdown frequently results in the product being dimensionally correct, apart from the minor diameter, which may be slightly oversize due to a flattening of the crest radius on the wheel with consequent flattening of the root radius on the workpiece. Such an error is corrected by lapping the root of the thread on the workpiece with a length of soft copper or



(a)

(b)

(c)

FIG. 80. EXAMPLES OF FAULTY SURFACE FINISH

(*a*) Chatter Marks Caused by Glazing or Loading of Wheel.
(*b*) Commercial Grinding without Filtered Coolant.
(*c*) Same Piece—Commercial Grinding with Filtered Coolant.

(*By courtesy of The Carborundum Co.*)

brass wire of the same radius as is required on the thread root. The wire is wrapped around the root diameter of the work, the free ends being held by hand to enable the coiled wire to exert a pressure as the work is rotated at about 10 ft per min. A little abrasive paste may be applied if more than about 0·001 in. is to be removed from the minor diameter of the work.

As much care should be taken in producing an accurate thread on the lap as would be devoted to obtaining an accurate profile on the abrasive wheel and workpart. Any errors of size, form, and pitch which are present in the lap will be transferred to the workpart.

The Carborundum Company's Recommendations. An allowance of 0·0002 in. is sufficient for hand lapping *plug gauges* when the ground surface is excellent. The lap should be of the split adjustable ring type, of grey iron. The gauge should be rotated and the lap oscillated over its surface using abrasives H240–WF for rapid stock removal, or H500–WF for high finish. Excessive pressure between the lap and the gauge may cause crushing of the abrasive. To polish the gauge it is recommended that compound 2A700–WP be applied. When it has dried the gauge can be buffed with a clean, dry, soft cloth.

Similar procedure enables successful lapping of *thread gauges*, except that threads of appropriate pitch and form are cut in the working surface of the lap. The direction of rotation of the gauge should be reversed in order to lap both thread profiles equally and the lap is returned to the starting point. The grade of compound recommended depends on the number of threads per inch—

10 t.p.i. and coarser	K320–WP
Finer than 10 t.p.i.	K500–WP

For extra-fine work follow on with 2A700–OF.

CHAPTER XIII

CALCULATING PRODUCTION TIMES

WHEN dealing with large batches of work it is frequently necessary to give an estimate of the number of work-hours required for the completion of a specified number of parts. Of course, it may be possible to base the estimate on records made previously, when handling workparts of similar type. If no such figures are available the estimate is usually arrived at after a time-study of the production of the first few workparts ground. This entails obtaining the *floor-to-floor time*.

FLOOR-TO-FLOOR TIME. The floor-to-floor time is the interval of time that elapses between picking up an unthreaded blank and removing it from the machine completely thread-ground.

The floor-to-floor time of a job on which the entire depth of thread is ground in one cut, or pass, includes the time taken to cover the following thirteen items—

(1) Picking up the workpart and loading it into the machine. This may entail placing the part between the machine centres, or in a chuck, collet, or work-holding fixture.

(2) Placing safety- and splash-guards in position.

(3) Applying coolant supply.

(4) Putting the work traverse into motion.

(5) Setting the feed and size control mechanism.

(6) The "idle time" taken when bringing the grinding wheel into contact with the workpart.

(7) The actual grinding time.

(8) The second period of idle time, i.e. the time that elapses from the instant when the grinding wheel leaves the work until the table traverse reaches the end of its stroke.

(9) Backing the grinding wheel away from the work. Depending upon the type of machine, this operation may be either manual or automatic.

(10) Returning work table to starting position.

(11) Disengaging coolant supply.

(12) Removing splash-guards.

(13) Unloading the work from the machine.

NOTE

Operations (4) to (10) would be repeated if the whole depth of thread necessitated more than one cut.

Additional time will be needed (1) if the work has to be inspected before the final cut, (2) for truing the thread form on the wheel, (3) for making any necessary adjustments.

FLOOR-TO-FLOOR TIME AND ACTUAL GRINDING TIME. It is useful to note the difference between these two times.

The *grinding time* is the time during which the grinding wheel is in contact with the work.

To visualize the difference between grinding time and floor-to-floor time, imagine a workpart on which a very short length of thread is to be ground. The job may be large, heavy, and awkward to handle, so that as much as twenty to thirty minutes may be consumed in loading it into the machine and in other preliminaries—yet the actual grinding time may be less than a minute. Obviously, then, the extent of the difference between floor-to-floor time and grinding time depends on factors peculiar to the type of work and the machine.

The authors picture the essential objects of *time study* as being (1) to eliminate wastage of time and effort, (2) to ensure that minimum time is taken to produce a workpart capable of fulfilling requirements, (3) to achieve quality and quantity at minimum cost.

A *motion study* expert pays special attention to the human movements used in operating a machine and classifies these movements into those involved in the set-up and those in the actual thread-grinding operation. Modern grinding machines have controls placed with due regard to economy in the operator's movements.

Quality, the factor of first importance, is linked closely with the actual grinding time. The latter is dependent primarily upon the work speed, the lead, and the length of thread. *Where a single-rib wheel is employed*, the grinding time is determined thus—

$$\begin{matrix}\text{Grinding time}\\ \text{(in minutes)}\end{matrix} = \frac{\text{length of grinding traverse (in inches)}}{\text{r.p.m. of work} \times \dfrac{1}{\text{No. of t.p.i.}}}$$

(t.p.i. = threads per inch)

EXAMPLE

Grinding traverse $\frac{3}{4}$ in.; Work spindle makes 6 r.p.m.; Thread has 14 t.p.i.

$$\text{Grinding time} = \frac{\frac{3}{4}}{6 \times \frac{1}{14}} = 1\tfrac{3}{4} \text{ min.}$$

NOTE

A work speed of 6 r.p.m. may appear low to some readers. However, the job referred to in the preceding example was produced very successfully at that work speed on a Jones and Lamson machine having work speeds of 0·6 r.p.m. to 150 r.p.m. graded as follows—

0·6	2·9	8·0	16·0	41
0·8	3·0	9·0	19·5	49
1·2	4·0	10·0	21·0	59
1·5	5·0	11·0	23·5	72
1·8	5·6	12·0	28·0	105
2·0	6·0	13·0	30·0	150
2·6	7·6	14·0	34·0	

GRINDING, TABLE, AND IDLE TRAVERSES

(1) The *grinding traverse* (also called *work traverse*) must not be confused with *table traverse*. The length of the grinding traverse is the whole longitudinal distance which the work travels while in contact with the wheel.

Where a single-rib wheel is used the length of the grinding traverse equals the axial length of the ground thread. Where a multi-rib wheel is used for plunge-cut grinding the grinding traverse may amount to little more than the lead of the thread being ground.

(2) The *table traverse* is the total longitudinal movement or "stroke" of the table. This is equal to the *grinding traverse* plus the *idle traverse.*

(3) *Idle traverse* is the distance which the table moves or "traverses"

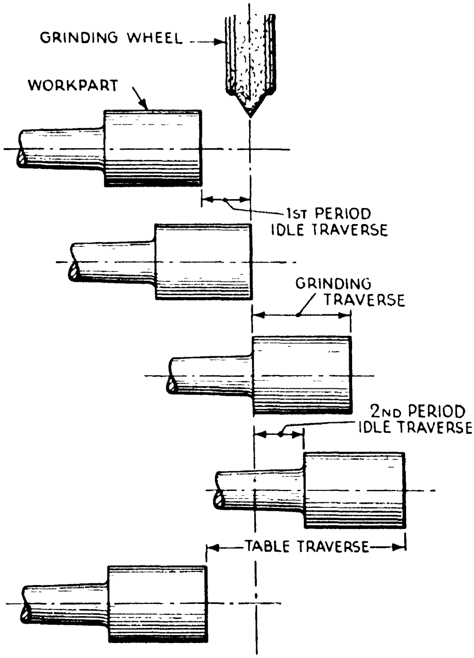


FIG. 81. ILLUSTRATING VARIOUS TRAVERSES

from the starting position until the work contacts the grinding wheel, plus the distance moved by the table after the grinding wheel leaves the work.

A Detailed Example. The following example emphasizes the saving in time that can result from analysing every phase of the grinding operation. It also outlines the method of splitting the floor-to-floor time into separate components.

Job: Two-start worm. Pitch 0·0833 in. Lead 0·1667 in. Major diameter ground in previous operation. Pitch diameter 0·3134 in. Minor diameter 0·252 in. Depth of thread 0·0572 in. Double depth 0·1144 in. Pressure angle 20°. Length of threaded portion 0·6 in. Tolerances: pitch diameter $\pm 0{\cdot}001$ in.; minor diameter $\pm 0{\cdot}002$ in.; pitch error 0·0002 in.; angular error ± 6 minutes of arc.

Machine: Jones and Lamson.

Wheel: Single Rib.

Previous Floor-to-floor Time: 6 min. 17 sec., taking four cuts, wheel being trued after every cut.

Alterations Made to Original Set-up

(1) Grinding oil replaced by less viscous emulsion.

(2) Vitrified grinding wheel replaced by a resinoid bakelite-bond grinding wheel.

(3) Diamond tools re-lapped.

(4) Coolant supply nozzles modified to avoid spray and to increase volume of coolant. This adjustment obviated the need for splash guards.

(5) Quicker-acting work-holding fixture installed.

(6) Whole depth of thread ground in one cut.

The following list shows the sequence of operations with tabulated single operation times and, finally, the floor-to-floor time—

	Minutes	Seconds
Load part to machine	0	4
Start motive cycle	0	2
Idle time	0	2
Grinding time. First start of thread	0	19
Idle time	0	2
Wheel back-away	0	2
Table return to starting point	0	7
Rotate spring-operated fixture for second start of thread	0	5
Start motive cycle	0	2
Idle time	0	2
Grinding time. Second start of thread	0	19
Idle time	0	2
Wheel back-away	0	2
Automatic truing of wheel	0	7
Table return stroke	0	9
Unload part from machine	0	4
Floor-to-floor time	1 min.	30 sec.
Original time	6 min.	17 sec.
Saving in time	4 min.	47 sec.
Difference between grinding time and floor-to-floor time		52 sec.

The Most Economical Time. This cannot be found theoretically—but only by trial and experiment. For any given job the most economical grinding time can be found only after reference to various factors, e.g.—

(1) Amount of stock removed per unit wear of grinding wheel.

(2) Useful life of the grinding wheel (in work-hours) per number of wheel dressings and feed of the diamonds or crushing rollers.

(3) Percentage of faulty work.

(4) Wear and tear of equipment, etc.

CHAPTER XIV

THREAD-MEASURING AND GAUGING EQUIPMENT BRIEFLY DESCRIBED

THIS chapter, giving very brief details* of equipment used for controlling the dimensions of thread-ground workparts, serves as an introduction to the subsequent chapter on thread measurement by the "wire" method. The measurement of screw and worm threads is nowadays a highly complex subject impossible to describe in detail in a single chapter. The gauges and instruments described in the following notes typify those most generally used.

RING SCREW GAUGES. These are extensively used for checking *male* threads. A "Go" ring-screw gauge is used to ensure that workparts do not exceed the *maximum* prescribed dimensions. The form of thread is that of the basic or standard full form, and the "Go" gauge checks the major, minor, and pitch diameters and takes full cognizance of errors in form and pitch. The "Go" gauge is often referred to as an "acceptance gauge"; thus, a workpart that will assemble with the "Go" gauge will also assemble with its mating female thread. A ring-screw gauge is shown in Fig. 82.

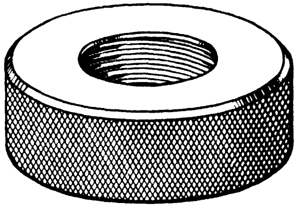


FIG. 82. RING-SCREW GAUGE

A "Not Go" ring-screw gauge is used to ensure that workparts are not ground smaller than the *minimum* prescribed dimensions. The form of thread is truncated at the crests and clearance is provided at the roots. Contact between the gauge and the workpart is thus restricted to the flanks of the thread. In addition, the number of complete thread convolutions is restricted to two or three so that errors in pitch do not influence assembly of the gauge with the workpart.

The forms of thread in a "Go" and a "Not Go" ring-screw gauge are shown in Fig. 83. Ring-screw gauges may be "solid" or "split," the latter type having a means of size adjustment.

CALIPER SCREW THREAD GAUGES. Two types of caliper screw gauges are widely used for checking *male* screw thread diameters. The "flat jaw" type is distinguishable from the "roller anvil" type by the shape of the gauging anvils.

The Wickman Flat-jaw Type Caliper Screw Gauge is shown in Fig. 84. The anvils, which have a chaser-like appearance, are held rigidly

* Readers requiring a more comprehensive description of gauges and their uses should refer to *Engineering Inspection*, by A. C. Parkinson (Pitman).

so that they can neither turn nor tilt. Each pair can be adjusted, inwards or outwards, to within 0·0001 in. to a setting piece, usually a screw-setting plug gauge. As will be seen in Fig. 83 the front, or "Go," anvils have full thread forms, whereas the rear, or "Not Go," anvils have truncated crests and clearance provided at the roots. The "Go" anvils are set to the nominal effective diameter of the thread to be gauged and are of sufficient width to cover the engagement of the screw. In brief, then, the front anvils ensure that no element of the thread is oversize, and the rear anvils that the simple effective diameter is not undersize. The threads on the anvils are relieved so that there

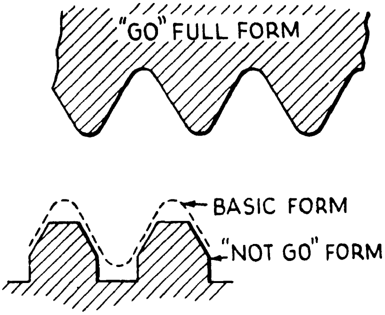


FIG. 83. FORMS OF THREADS IN "GO" AND "NOT GO" SCREW GAUGES

is no interference due to the helix angle of the thread being inspected. In this way inspection takes place purely on an axial plane of the thread, at which place the true thread form is located. Since there is no interference due to helix angle the same gauge can be used for both right- and left-hand threads.

The Matrix Roller-anvil Type of Caliper Screw Gauge is shown in Fig. 85. This consists essentially of a rigid frame and two pairs of rollers. At the front is a pair of full-form "Go" rollers; at the back a pair of "Not Go" rollers having threads with truncated crests and extended roots, so that contact between the workpiece and the rollers takes place only on the flanks of the thread. The rollers are of annular thread form, corrected to compensate for helix angle interference. They are mounted on eccentric studs locked in position to the frame, so that whilst being retained on their studs they are free to rotate. The makers recommend that for setting the rollers to give the desired tolerances a double-ended setting plug be used. Readers interested in caliper screw gauges will find it useful to read *An Efficient Gauging System* (Alfred Herbert, Ltd.), and The Wickman Thread Caliper Gauge Catalogue.

The forms of thread on "Go" and "Not Go" anvils are shown in Fig. 83.

At (*b*) in Fig. 85 is shown a double-ended setting plug on which the roots and crests of the threads are removed so that only the effective

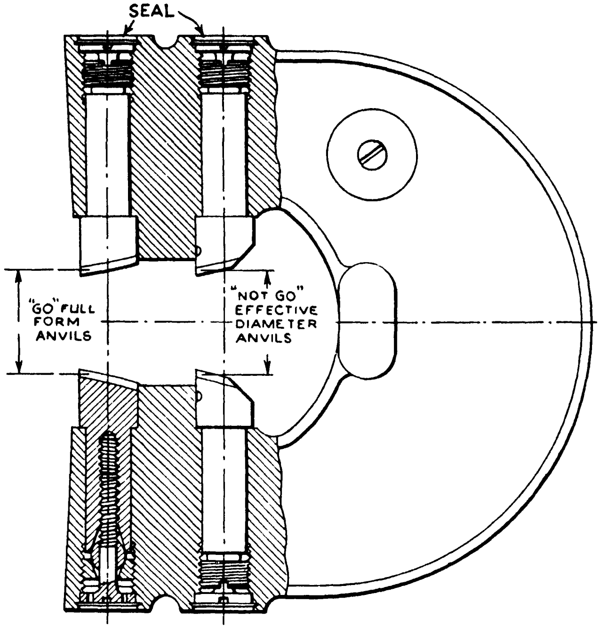


FIG. 84. ADJUSTABLE TYPE THREAD GAUGE OF WICKMAN TYPE

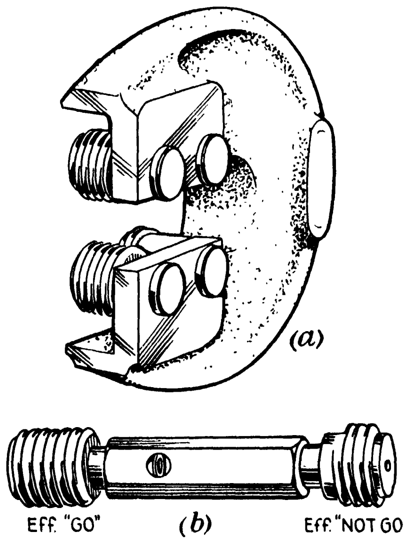


FIG. 85. MATRIX ROLLER TYPE ADJUSTABLE LIMIT THREAD GAUGE AND SETTING PLUG

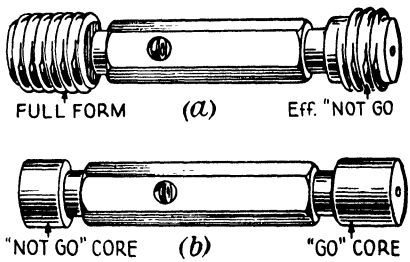


FIG. 86. TYPICAL LIMIT GAUGES
(a) Plug Screw Gauge, (b) Plug Gauge.

diameter is used when setting the rollers. The plug dimensions are arranged to set the "Go" rollers to nominal size and the "Not Go" to the nominal size minus the tolerance prescribed. These setting plugs are manufactured by the Coventry Gauge & Tool Co., Ltd.

PLUG SCREW GAUGE. A plug screw gauge with "Go" and "Not Go" diameters at opposite ends is used for checking *maximum* and *minimum* diameters of female threads. The "Go" end has a full-form thread and the "Not Go" end has a truncated form of thread. See Fig. 83. A typical plug screw gauge is shown in Fig. 86 (*a*).

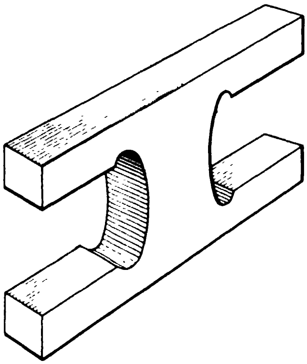


FIG. 87. GAP GAUGE

PLUG GAUGE. A plug gauge with plain "Go" and "Not Go" diameters at opposite ends, see Fig. 86 (*b*), is used for checking minor or "core" diameters of *female* threads. The "Go" end is made equal to the *minimum* minor diameter, the "Not Go" end equal to the *maximum* minor diameter.

GAP GAUGE. A "Go" and "Not Go" gap gauge is used for checking the major diameters of *male* threads. The "Go" gap is made equal to the *maximum* prescribed diameter, the "Not Go" end equal to the *minimum* major diameter. A typical gap gauge is shown in Fig. 87.

Summarized Notes on Gauges

(1) A "Go" gauge should assemble freely (without forcing) with the workpart to be tested over its whole length.

(2) A "Not Go" gauge should not assemble with the workpart.

A "Not Go" effective diameter plug gauge may possibly be allowed to screw one turn, or at most two turns, into the screwed hole being inspected.

(3) All "Go" gauges should be re-examined periodically as a check on their wear. It is evidently necessary to discard (as production gauges) workshop gauges as soon as they begin to pass components outside the limits specified.

(4) Workshop gauges may be considered *production gauges*, for they are used in the shops during the manufacture of workparts. So as to provide a margin of safety, they are made to sizes so that components are checked to limits which are slightly inside the limits shown on the drawing.

SCREW-THREAD MICROMETER. This measuring instrument provides an accurate and convenient means of measuring simple effective diameters of male threads. Reading the micrometer graduations is carried out in the same way as with the more conventional type of micrometer. Screw-thread micrometers are marketed for prescribed ranges of thread pitches, each micrometer being suitable for one thread angle, usually 60° or 55°. The male anvil is truncated at the apex, the female anvil being cleared at the root and truncated at the crests. A typical screw-thread micrometer is shown in Fig. 88.

GEAR-TOOTH VERNIER CALIPER. See Fig. 89. This graduated

caliper gauge is useful for measuring the thickness of worm threads. The graduations allow measurements to be taken within 0·001 in. The gear-tooth vernier caliper is fully described in *Engineering Inspection*, A. C. Parkinson (Pitman).

THE ZEISS MICROMETER. The principle embodied in the "wire" method of thread measurement is incorporated in many forms of direct-reading instruments. A typical example is the Zeiss micrometer shown

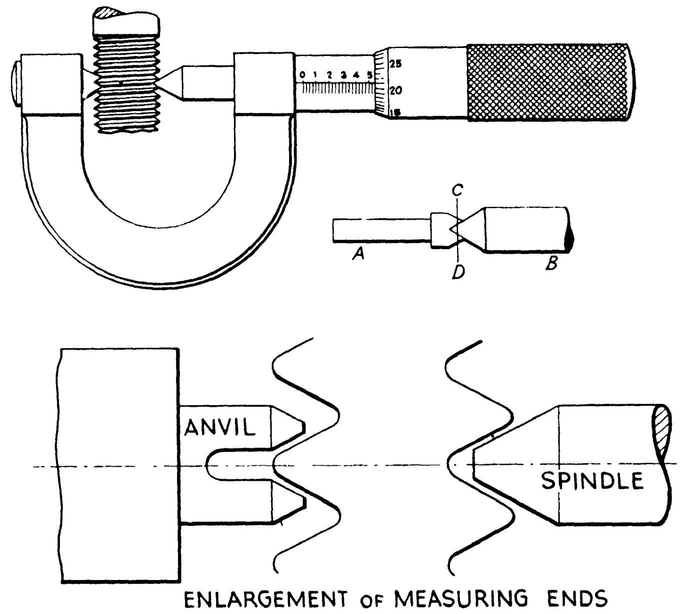


FIG. 88. THREAD MICROMETER FOR VEE THREADS

in Fig. 90. The special purpose anvils are designed to hold thread measuring cylinders for measuring simple effective diameters of male screw threads. Measurements are recorded by graduations on both thimble and barrel in addition to those recorded on a scale in the main frame of the micrometer.

THE TAVANNES THREAD-MEASURING MICROMETER. This instrument, illustrated in Fig. 91, has two *wire holders*, one carrying a single wire and the other two wires. These wire holders are readily set on the anvils of the micrometer, to which they are fastened by small screws. Details are obtainable from the Adam Machine Tool Co., Ltd., London, N.4.

VEE PIECES OR PRISMS. These are used on thread-measuring machines for measuring minor diameters and depths of threads on male

screws. The vee pieces are hardened-steel prisms of approximately triangular shape, having an included angle of about 45° ($45^\circ\,{}^{+0^\circ}_{-2^\circ}$ is recommended by the N.P.L.) so that they clear the flanks of the threads. Their working edges are rounded with a radius smaller than that at the roots of the threads being measured. In use they are usually suspended from supports so that they may readily be placed in contact with the screw. Firms specializing in the manufacture or supply of thread-measuring equipment supply these prisms in a range of sizes. As shown in Fig. 92, two prisms are employed as a pair, their flat bases bearing against the flat ends of the micrometer spindle and anvil.

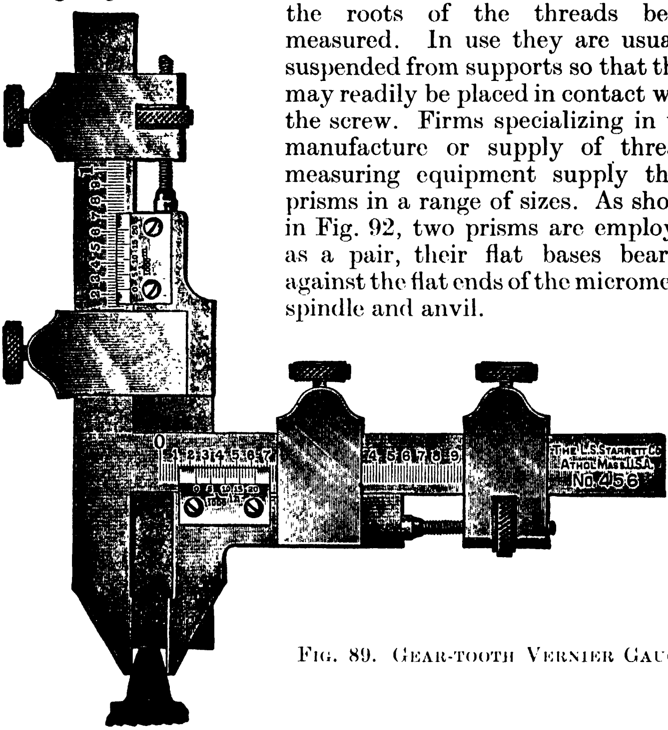


Fig. 89. Gear-tooth Vernier Gauge

The procedure of core measurement by this method, on a diameter-measuring machine, is usually as follows—

(1) The micrometer head is moved until the pointer of the indicator coincides with the fiducial mark and a reading is taken when the prisms bear on the core of the workpiece as shown. The reading may be called R_G.

(2) The workpiece is taken from the machine and replaced by a plain cylindrical plug gauge the diameter of which approximates to the core diameter of the screw to be measured. When the rounded edges of the prisms make contact with the plug a reading is taken. This may be called R_S.

Suppose D = diameter of plain plug employed. Then, Minor dia. of screw $= D + R_G - R_S$.

The actual sizes of the vee pieces do not require to be known, neither must they necessarily be of the same size. It is essential, however, that both vee pieces be uniformly parallel throughout their lengths, i.e.

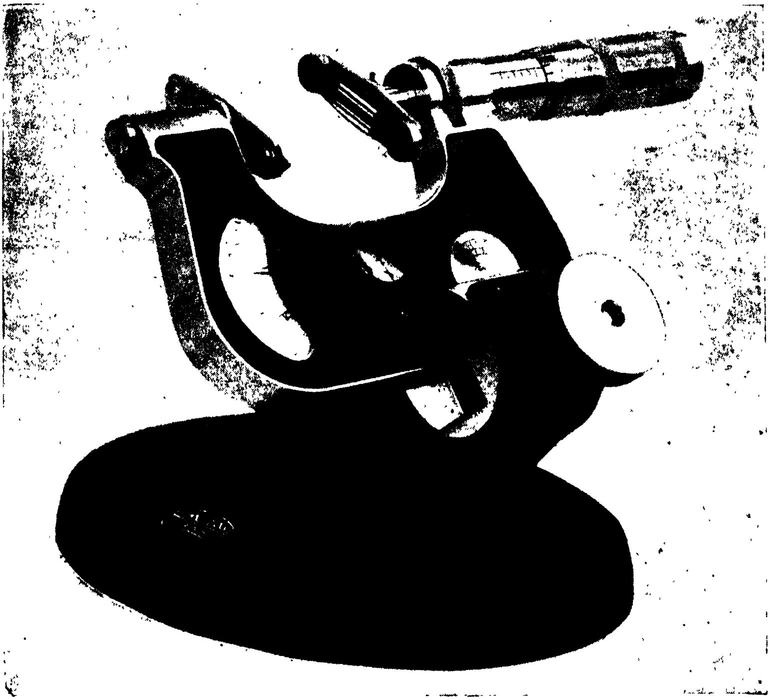


FIG. 90. THE ZEISS MICROMETER
(*By courtesy of Messrs. Alfred Herbert, Ltd.*)

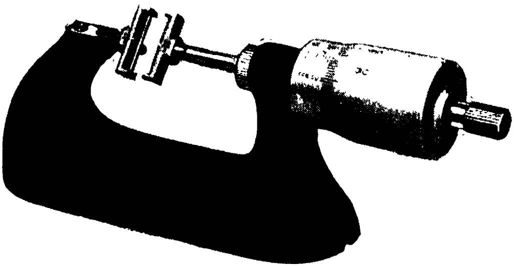


FIG. 91. THE TAVANNES THREAD-MEASURING MICROMETER
(*By courtesy of Adam Machine Tool Co., Ltd.*)

the front measuring "edge" must be parallel to the back face, and both must be straight.

THREAD-DIAMETER MEASURING MACHINE. Machines of the type shown in Fig. 93, are fully described in *Notes on Screw Gauges*

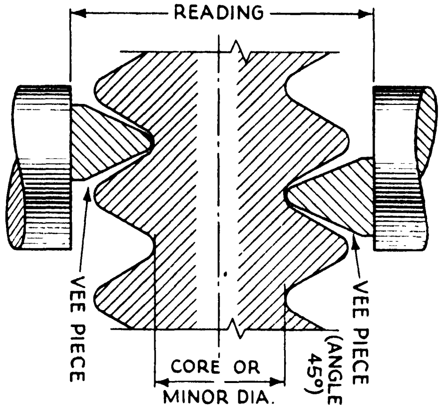


FIG. 92. VEE PIECES USED FOR MEASUREMENT OF MINOR DIAMETER

(H.M.S.O.). The close-up view, Fig. 94, shows the use of thread-measuring cylinders in conjunction with the diameter-measuring machine for measuring simple effective diameter of a screw thread.

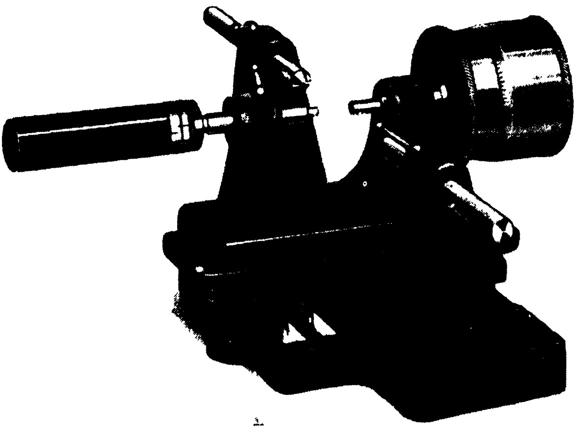


FIG. 93. P.V.E. DIAMETER-MEASURING MACHINES
(*By courtesy of the Makers*)

Measurements within 0·0001 in. are obtained on major, minor, and pitch diameters. The machine consists of a base, intermediate slide, and a top slide or carriage. The micrometer is fitted with a large drum graduated in 0·0001 in. The mechanical indicator is fitted with

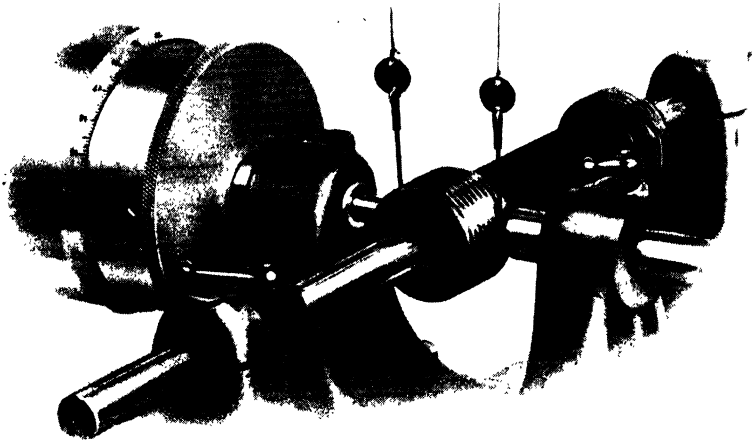


FIG. 94. CLOSE-UP VIEW OF P.V.E. DIAMETER-MEASURING MACHINE EMPLOYED TO MEASURE THE EFFECTIVE DIAMETER OF A SCREW PLUG GAUGE WITH THE AID OF CYLINDERS OR WIRES

(*By courtesy of the Makers*)

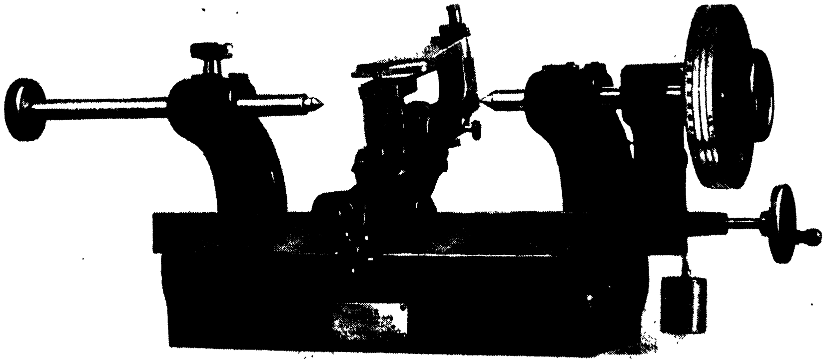


FIG. 95. P.V.E. SCREW-PITCH MEASURING MACHINE

(*By courtesy of the Makers*)

A test on a screw-pitch measuring machine is more dependable than the method in which pitch is found by measuring the displacement of a nut per revolution of the screw. Periodic errors which occur during the length of the nut do not affect the extent of its displacement and thus do not reveal themselves. However, the method does give the effective pitch of the combined screw and nut, which for many purposes is all that is required.

a fiducial indicator which operates under a pressure of about 8 oz. The machine was designed at the National Physical Laboratory and is obtainable commercially in two or three sizes to accommodate screws up to about ten inches in diameter.

Figs 93 and 94 illustrate Diameter-measuring Machines made by the Pitter Gauge and Precision Tool Co., Ltd., Leatherhead, Surrey, a British firm well known for its pioneer work in the production of accurate gauges and precision-measuring equipment.

THREAD-PITCH MEASURING MACHINE. Fig. 95 shows the well-known P.V.E. thread-pitch measuring machine designed by the National Physical Laboratory and made by the Pitter Gauge and Precision Tool Co., Ltd. The machine is fully described in *Notes on Screw Gauges* (H.M.S.O.). Pitch measurements within accuracy of 0·0001 in. and less are readily obtained on both male and female threads. Male screws are mounted between the centres of the machine. Female screws are mounted on a specially designed chuck. The indicator, carrying a stylus bearing on the flanks of the thread being measured, is carried on a slide mounted on steel balls. The act of rotating the micrometer causes the indicator to move axially in relation to the screw being measured and thus causes the stylus to contact successive thread grooves. Pitch measurement is obtained from the micrometer graduations when the indicator reads zero. The travel of the micrometer is 1 in. Different styluses are used for different thread pitches.

OPTICAL CONTOUR PROJECTORS. Many types of optical measuring machines are in use for measuring the contours of threads. Typical of these is the *Vickers Contour Projector* shown in Fig. 96. Various firms manufacture contour projectors, some compact, some very large. All, however, have this in common: they provide a means of inspection of size and form without mechanical contact between the work and the measuring device, in a manner at once extremely accurate and relatively inexpensive. Readers interested further in inspection of threads by optical projection apparatus will find illustrated descriptions of various projectors designed at the National Physical Laboratory in *Notes on Screw Gauges* (H.M.S.O.). Further illustrated descriptions are given in *Engineering Inspection*, by A. C. Parkinson (Pitman).

The principal uses of the projector shown in Fig. 96 are—

(1) The measurement of magnified silhouettes of templates and other plane objects, or their comparison with translucent masters drawn to an enlarged scale.

(2) The measurement of screw threads, or their comparison under magnification.

The design is such that the object and image planes are close together. Since projection, in this model, is from *beneath* the screen, the observer does not tend to produce shadows across the projected image when taking measurements with a rule, protractor, or the like. The instrument is constructed to project an image whose size bears a fixed relationship to that of the object, i.e. exactly 10, 25, or 50 times.

The dimensions of the object may be obtained in two ways:

(1) By measuring the projected image and dividing the result by the appropriate magnification factor, or

(2) By translating the projected image in relation to a fiducial line on the projection screen, and by noting on the micrometer screws of the measuring stage the value of the movements necessary to bring this about.

In the first method, measurement of the image may be made conveniently with a glass scale, or from a template made to the appropriate scale. Such templates may be produced photographically from a master component, drawn on tracing paper, or formed out of sheet metal.

THE O.M.T. OMTIMETER. This is a high-precision optical com-

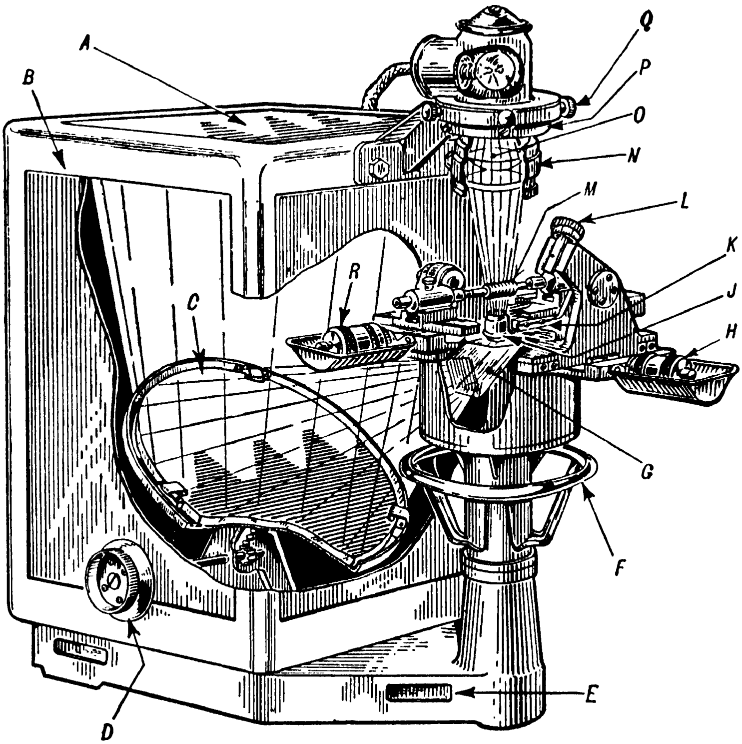


FIG. 96. VICKERS CONTOUR PROJECTOR

(*By courtesy of the Makers*)

A = Projection screen.
B = Camera.
C = Mirror.
D = Adjustment for magnification.
E = Cast-iron base.
F = Focusing wheel.
G = Roof prism.
H = Transverse micrometer.
J = Projection anastigmat.
K = Ball-bearing slides.
L = Helix angle micrometer.
M = Screw thread under test.
N = Condenser spiral focusing sleeve.
O = Condenser.
P = Centring screws for condenser.
Q = Centring screws for lamp.
R = Longitudinal micrometer.

parator equally useful in the standards room and in production checking. It is obtainable as a *vertical omtimeter* or as a *horizontal omtimeter*. Perhaps one of the most interesting and characteristic uses of the horizontal model—in which the measuring axis is horizontal—is in measuring the effective diameters of ring-screw gauges. A master "screw form" or "reference standard" is first built up from

slip gauges and vee-notched jaw blades. A range of ball-end tips is supplied for use in a manner similar to measuring wires or cylinders for external thread measurement. The internal fingers fitted with ball-ended tips are then used to set the instrument to zero against the built-up master. The master is then replaced by the screw-ring gauge

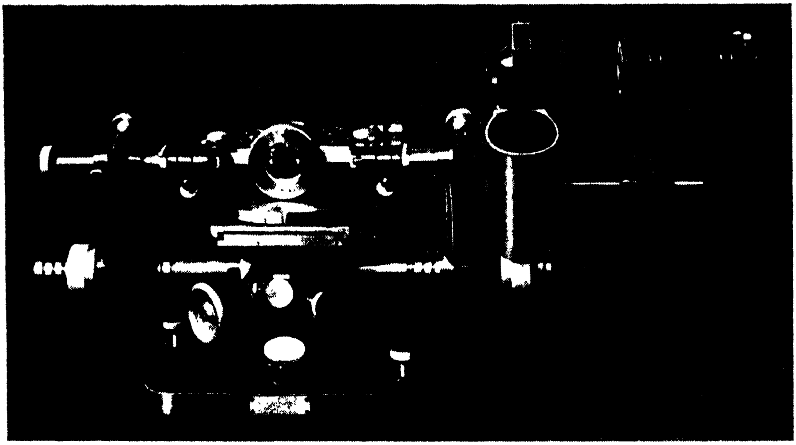


FIG. 97. THE O.M.T. OMTIMETER
(By courtesy of the Makers)

and comparative measurements are shown on a graduated scale. A measuring pressure of 8 to 10 ounces is arranged. Fig. 97 shows the O.M.T. Horizontal Omtimeter, detailed particulars of which are obtainable from Optical Measuring Tools, Ltd., Slough, Bucks. In the illustration the Omtimeter is shown as arranged to check the effective diameter of a ring gauge.

As will be seen from the illustration, the essentials of this comparator comprise an optical measuring head and a tailstock mounted over universally adjustable work-tables on which the object to be measured is placed. The effective diameter of internal precision screws can be measured to 0·0001 in.

CHAPTER XV

MEASURING THREADS BY WIRE METHODS

POSSIBLY the most important thread dimensions are the effective diameter or pitch diameter, and the thread angle. Between them they determine the quality of the fit between the thread and the nut. The crests and roots need not fit in two mating members, for clearance is generally permitted, indeed often required, at those parts.

EFFECTIVE DIAMETER. The first widely accepted standard system was the Whitworth, in which no allowance was made for top and bottom clearance; that is, the original design called for tops and bottoms of threads fitting perfectly around a certain-sized radius—an impossibility in commercial production. Then again, in the absence of instruments for the precise measurement of diameters, the whole system fell far short of real interchangeability. Some twenty years after the introduction of the Whitworth thread the Franklin Institute of America introduced the Sellers thread, having a 60° angle with flat crests and roots. This was considered more economical to produce than a thread with rounded crests and roots. However, in this case also, no allowance was made for top and bottom clearance and, of course, there was still no generally available equipment for the precise measurement of the various thread elements. Nowadays, of course, we have elaborate systems of tolerances on the various diameters to yield different classes of fits, and a no less elaborate range of measuring devices to facilitate accurate production, i.e. production to limits deemed suitable in relation to the purpose the threaded items are designed to serve. One of the first things learned about modern screw-thread work is that no good purpose is served by making threads bind at top and bottom and that one of the most important dimensions is the effective diameter.

To quote from the U.S. Bureau of Standards Handbook, No. H28: *the so-called "three-wire" method of measuring pitch diameter has been found to be the most accurate and satisfactory when properly carried out, and is recommended for universal use in the direct measurement of thread-plug gauges.*

MEASUREMENT BY USING CYLINDERS OR WIRES. It will be clear that a cylinder of fixed diameter will always lie at a certain depth inside a groove. The terms *cylinders*, *pins*, *needles*, *wires* are all employed to describe the cylindrical measuring pieces employed. We assume in these remarks that the groove has straight sides, i.e. that the flanks of the threads are "straight" in profile and are thus tangential to both the root and crest arcs. If the flanks are badly shaped it is obvious that the cylinder or wire will lie nearer to, or farther from, the thread axis than it should. The use of wires, or small cylinders of correct and uniform dimensions, enables us to check the form of the thread whilst measuring its *simple effective diameter.*

Wire measuring methods, which are commonly used for checking ground threads, permit of (1) *direct* or *absolute* measurements, or (2) *comparative* measurements.

To illustrate the second case, suppose we have to check a 1-in. B.S.W. screw. We can first take the measurement over the wires on a screw-plug gauge having the required pitch and diameter, i.e. if we know that its effective diameter and thread angle are correct within prescribed limits. Next, we can use the same wires to check the effective diameter of the workpiece. This is a *comparison method*. For production checking, a dial indicator or amplifier can be used.

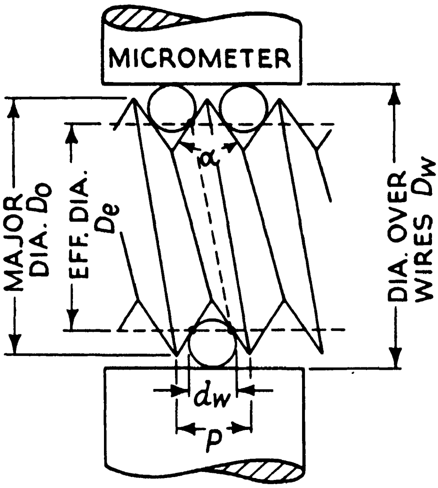


FIG. 98. ILLUSTRATING THE THREE-WIRE SYSTEM, USING BEST SIZE WIRES

This can be set up to a master of known size or to slip or block gauges. Anvils on amplifiers or dials ("clocks") must be flat and hard and may require frequent lapping, as the wires tend to cut grooves in anvils, thus affecting the size indicated.

THREE-WIRE SYSTEM. From Fig. 98 it will be seen that two wires of known and equal diameter are placed in contact with the sides of the thread groove on one side and one, of the same diameter and coming immediately between them, on the other. A micrometric measurement is taken over the wires and a calculation made in reference to a formula. The formulae employed are based either upon (1) outside or major diameter, or (2) effective diameter. In these notes formulae based on both methods are given.

The degree of exactitude obtained in calculating dimensions over wires depends upon how far all possible sources of error are taken into account, e.g. whether or not the formula used has any relationship to the obliquity of the wires as they lie in the thread spaces. The need for extreme accuracy is evidently greater in the case of single-piece screw-gauge inspection than in the case of mass-produced screwed components.

THE MATHEMATICAL BASIS OF THE WIRE MEASUREMENT METHOD—USING EFFECTIVE DIAMETER. The principles of measurement over wires can be shown by considering the general case, as illustrated in Fig. 99, of a vee-thread. Note that α = the whole thread angle (55° in the case of a Whitworth thread).

$$AE = AC \operatorname{cosec} \frac{\alpha}{2} = r \operatorname{cosec} \frac{\alpha}{2}$$

$$D = EF \cot \frac{\alpha}{2} = \frac{P}{2} \cot \frac{\alpha}{2}$$

$$GE = \frac{D}{2} = \frac{P}{4} \cot \frac{\alpha}{2}$$

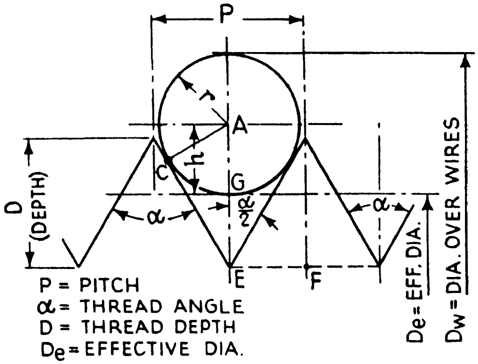


FIG. 99. ILLUSTRATING FORMULA FOR CALCULATING DIAMETER OVER WIRES

$$\begin{aligned} h &= AE - GE \\ &= \left(r \operatorname{cosec} \frac{\alpha}{2}\right) - \left(\frac{P}{4} \cot \frac{\alpha}{2}\right) \\ D_w &= D_e + 2h + 2r \\ &= D_e + 2\left\{\left(r \operatorname{cosec} \frac{\alpha}{2}\right) - \left(\frac{P}{4} \cot \frac{\alpha}{2}\right)\right\} + 2r \\ &= D_e + 2r\left(1 + \operatorname{cosec} \frac{\alpha}{2}\right) - \frac{P}{2} \cot \frac{\alpha}{2} \\ &= D_e + d_w\left(1 + \operatorname{cosec} \frac{\alpha}{2}\right) - \frac{P}{2} \cot \frac{\alpha}{2} \end{aligned}$$

FORMULAE BASED ON OUTSIDE DIAMETER (MAJOR DIAMETER)

Again refer to Fig. 99.

D_w = Diameter over the wires
D_o = Major or outside diameter, over crests of thread.
(The *standard basic major diameter*, or *nominal diameter*)

$P =$ pitch of thread
$d_w =$ diameter of wire, as determined by careful measurement.

$$\text{Then, } D_w = D_o - AP + Bd_w$$

For **Whitworth threads**

$$A = 1\cdot6008, \; B = 3\cdot1657$$
$$\text{Thus } D_w = D_o - 1\cdot6008\, P + 3\cdot1657\, d_w$$

Values of A and B for other threads are shown below.

For **U.S. National threads**

$$D_w = D_o - 1\cdot5155\, P + 3\cdot0000\, d_w$$

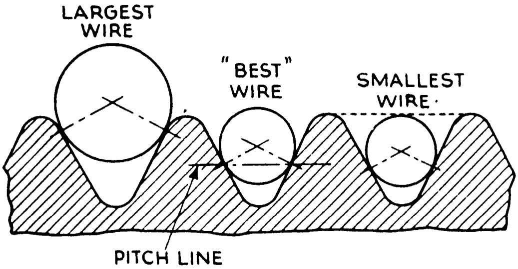


FIG. 100. EXTREME SIZES COMPARED WITH BEST-SIZE FOR WIRES OR CYLINDERS

For **B.A. threads**

$$D_w = D_o - 1\cdot7363\, P + 3\cdot4829\, d_w$$

For **International threads** (**S.I.**)

$$D_w = D_o - 1\cdot5155\, P + 3\cdot0000\, d_w$$

For **Löwenherz threads**

$$D_w = D_o - 1\cdot75\, P + 3\cdot2359\, d_w$$

For **Sharp vee threads**

$$D_w = D_o - 1\cdot732\, P + 3\cdot0000\, d_w$$

A table showing the values of constants $1\cdot6008\, P$ and $1\cdot5155\, P$ for 36 different pitches is given on page 141.

EXTREME SIZES OF MEASURING CYLINDERS. The following sizes are given in *Notes on Screw Gauges*—

Whitworth	Largest	diameter	$0\cdot853\, P$.	Smallest	diameter	$0\cdot506\, P$
B.A.	,,	,,	$0\cdot730\, P$.	,,	,,	$0\cdot498\, P$
C.E.I.	,,	,,	$0\cdot822\, P$.	,,	,,	$0\cdot466\, P$
System International	,,	,,	$1\cdot010\, P$.	,,	,,	$0\cdot505\, P$

For U.S. National threads a common workshop rule is: largest

cylinder = pitch of thread; smallest cylinder = half pitch of thread. The largest cylinder that could be used would rest on the extreme ends of the straight portions of the flanks of the thread. The smallest cylinder must come flush with the crests of the threads. See Fig. 100.

USEFUL TABLE OF CONSTANTS USED IN FORMULAE FOR WIRE MEASUREMENT OF THREADS

No. of T.P.I.	Whitworth	U.S. National	Whitworth	U.S. National	Sharp Vee
	$1 \cdot 6008\, P$	$1 \cdot 5155\, P$	$0 \cdot 9605\, P$	$0 \cdot 866\, P$	$1 \cdot 732\, P$
2½	0·6403	0·6062	0·3842	0·3464	0·6928
2¾	0·5821	0·5511	0·3493	0·3149	0·6298
3	0·5336	0·5052	0·3202	0·2887	0·5773
3½	0·4574	0·4330	0·2744	0·2474	0·4949
4	0·4002	0·3789	0·2401	0·2165	0·4330
4½	0·3557	0·3368	0·2134	0·1924	0·3849
5	0·3202	0·3031	0·1921	0·1732	0·3464
5½	0·2911	0·2755	0·1746	0·1575	0·3149
6	0·2668	0·2526	0·1601	0·1443	0·2887
7	0·2287	0·2165	0·1372	0·1237	0·2474
8	0·2001	0·1894	0·1201	0·1083	0·2165
9	0·1779	0·1684	0·1067	0·0962	0·1924
10	0·1601	0·1516	0·0961	0·0866	0·1732
11	0·1455	0·1378	0·0873	0·0787	0·1575
12	0·1334	0·1263	0·0800	0·0722	0·1443
13	0·1231	0·1166	0·0739	0·0666	0·1332
14	0·1143	0·1083	0·0686	0·0619	0·1237
15	0·1067	0·1010	0·0640	0·0577	0·1155
16	0·1000	0·0947	0·0600	0·0541	0·1083
18	0·0889	0·0842	0·0534	0·0481	0·0962
20	0·0800	0·0758	0·0480	0·0433	0·0866
22	0·0728	0·0689	0·0437	0·0394	0·0787
24	0·0667	0·0632	0·0400	0·0361	0·0722
26	0·0616	0·0583	0·0370	0·0333	0·0666
28	0·0572	0·0541	0·0343	0·0309	0·0619
30	0·0534	0·0505	0·0320	0·0289	0·0577
32	0·0500	0·0474	0·0300	0·0271	0·0541
34	0·0471	0·0446	0·0283	0·0255	0·0509
36	0·0445	0·0421	0·0267	0·0241	0·0481
38	0·0421	0·0399	0·0253	0·0228	0·0456
40	0·0400	0·0379	0·0240	0·0216	0·0433
42	0·0381	0·0361	0·0229	0·0206	0·0412
44	0·0364	0·0344	0·0218	0·0197	0·0394
46	0·0348	0·0329	0·0209	0·0188	0·0377
48	0·0334	0·0316	0·0200	0·0180	0·0361
50	0·0320	0·0303	0·0192	0·0173	0·0346

"BEST DIAMETER" WIRES, CYLINDERS OR NEEDLES. The "best diameter" cylinder touches the flanks of the threads at the pitch line. If this were always insisted upon, however, it would entail the provision of very accurately made cylinders for every pitch of every

thread form dealt with. The N.P.L. is prepared to certify cylinders to be used for any given screw thread, provided that such cylinders make contact with the flanks of the threads within a distance of one-tenth of the length of the straight portion of the thread on either side of the pitch line. That is to say the cylinders must touch the flanks *inside the middle fifth of the straight part of the flank.* In *Notes on Screw Gauges* the reader will find tables showing limits on diameters of cylinders for various pitches of Whitworth, Metric, and B.A. threads.

The following table is an example. It assumes the use of cylinders which touch the flanks of the threads inside the middle fifth of their straight portions.

N.P.L. TOLERANCE TABLE (P = Pitch)

Form of Thread	Dia. of Ideal Best-size Cylinder	Permissible Tolerance on Diameter	Limits for Diameters of Thread-measuring Cylinders
Whitworth . .	$0{\cdot}564\ P$	$\pm\ 0{\cdot}029\ P$	$0{\cdot}535 \times P$ $0{\cdot}593 \times P$
B.A. . . .	$0{\cdot}546\ P$	$\pm\ 0{\cdot}019\ P$	$0{\cdot}527 \times P$ $0{\cdot}565 \times P$
C.E.I. . . .	$0{\cdot}577\ P$	$\pm\ 0{\cdot}024\ P$	$0{\cdot}553 \times P$ $0{\cdot}601 \times P$
System International	$0{\cdot}577\ P$	$\pm\ 0{\cdot}043\ P$	$0{\cdot}534 \times P$ $0{\cdot}620 \times P$

N.P.L. SCHEDULE OF SIZES—THREAD-MEASURING CYLINDERS

This table, listing thirty ranges of cylinder sizes, was compiled to cover the measurement of all Whitworth screws from 3 to 48 t.p.i., S.I. screws with pitches from 8 to 0·05 mm and B.A. screws from No. 0 to No. 10. C.E.I. screws were not included owing to their more limited application. One set of cylinders may be used for two or more thread pitches and forms, e.g. 32-pitch Whitworth cylinders are also used for 0·75 mm Metric and No. 2 B.A.

Cylinders Marked	Suitable for Threads			Limits on Dia. of Cylinders Inches
	Whit. 55° t.p.i.	Metric 60° pitch mm	B.A. 47½°	
3 Whit.	3	8	—	0·184 to 0·190
3¼ ,,	3¼	7·5	—	0·170 ,, 0·176
3½ ,,	3½	7	—	0·158 ,, 0·164
4 ,,	4	6·5 and 6	—	0·139 ,, 0·145
4½ ,,	4½	5·5	—	0·122 ,, 0·128
5 ,,	5	5 and 4·5	—	0·107 ,, 0·110
6 ,,	6	4	—	0·090 ,, 0·096
7 ,,	7	3·5	—	0·078 ,, 0·084
8 ,,	8	3	—	0·067 ,, 0·073
9 ,,	9	2·75	—	0·0595 ,, 0·066

N.P.L. SCHEDULE OF SIZES—(*contd.*)

Cylinders Marked	Suitable for Threads			Limits on Dia. of Cylinders Inches
	Whit. 55° t.p.i.	Metric 60° pitch mm	B.A. 47½°	
10 Whit.	10	2·5	—	0·0535 to 0·0595
11 ,,	11	2·25	—	0·0485 ,, 0·054
12 ,,	12	2	—	0·0445 ,, 0·049
14 ,,	14	1·75	—	0·038 ,, 0·0425
16 ,,	16	1·5	—	0·0335 ,, 0·0365
18 ,,	18 and 19	—	—	0·0298 ,, 0·0312
20 ,,	20	1·25	—	0·0267 ,, 0·0297
22 ,,	22	—	—	0·0243 ,, 0·0269
24 ,,	24	—	—	0·0223 ,, 0·0247
26 ,,	26	1	No. 0	0·0210 ,, 0·0222
28 ,,	28 and 30	—	No. 1	0·0191 ,, 0·0198
32 ,,	32	0·75	No. 2	0·0168 ,, 0·0180
34 ,,	34 and 36	—	No. 3	0·0157 ,, 0·0163
40 ,,	40	—	No. 4	0·0137 ,, 0·0147
5 B.A.	—	—	No. 5	0·0122 ,, 0·0132
48 Whit.	48	0·5	No. 6	0·0111 ,, 0·0118
7 B.A.	—	—	No. 7	0·0099 ,, 0·0107
8 ,,		—	No. 8	0·0089 ,, 0·0095
9 ,,	—		No. 9	0·0081 ,, 0·0087
10 ,,	—	—	No. 10	0·0072 ,, 0·0078

CALCULATING DIAMETERS OF BEST-SIZE CYLINDERS

(1) **Single-start Threads.** The formula is—

$$d_w = \frac{0\cdot5 \times P}{\text{Cos}\,\frac{\alpha}{2}} = \frac{1}{2} P \times \sec \frac{\alpha}{2}$$

where α = the included angle of thread in an axial plane.

EXAMPLE

Whit. screw, pitch $\frac{1}{8}$ in., thread angle 55°.

$$d_w = \frac{1}{16} \times \sec 27\tfrac{1}{2}° = 0\cdot07047 \text{ in.}$$

(2) **Multi-start Threads.** The formula is—

$$d_w = \frac{\text{lead} \div \text{No. of starts}}{2\,\text{Cos}\,\frac{\alpha}{2}}$$

A 4-start metric thread of 12 mm lead could be measured with the same wires as a single-start thread of 3 mm lead or pitch, i.e. the wire diameter would be 1·732 mm.

WHITWORTH—BEST-SIZE CYLINDERS

d_w = Diameter of Best-size Cylinder.

T.P.I.	40	36	32	28	26	24	22	20	19
d_w (mm)	0·358	0·398	0·447	0·511	0·551	0·597	0·650	0·716	0·754
d_w (in.)	0·0141	0·0157	0·0176	0·0201	0·0217	0·0235	0·0256	0·0282	0·0297

T.P.I.	18	16	14	12	11	10	9	8	7
d_w (mm)	0·795	0·894	1·024	1·194	1·300	1·433	1·590	1·791	2·045
d_w (in.)	0·0313	0·0352	0·0403	0·0470	0·0512	0·0564	0·0626	0·0705	0·0805

T.P.I.	6	5	4	3½	3¼	3	2⅞	2¾	2⅝	2½
d_w (mm)	2·385	2·862	3·578	4·089	4·403	4·772	4·980	5·207	5·453	5·728
d_w (in.)	0·0939	0·1127	0·1409	0·1610	0·1734	0·1879	0·1961	0·2050	0·2147	0·2255

B.A.—BEST-SIZE CYLINDERS

DESIGNATION NO.	0	1	2	3	4	5	6	7	8	9	10
PITCH	1	0·9	0·81	0·73	0·66	0·59	0·53	0·48	0·43	0·39	0·35
d_w (mm)	0·546	0·492	0·442	0·399	0·361	0·322	0·290	0·262	0·235	0·213	0·191
d_w (in.)	0·0217	0·0195	0·0175	0·0158	0·0143	0·0128	0·0115	0·0104	0·0093	0·0084	0·0076

METRIC—S.I.—60°. BEST-SIZE CYLINDERS

PITCH (mm)	0·5	0·75	1	1·25	1·5	1·75	2	2·5	3
d_w (mm)	0·289	0·433	0·577	0·722	0·866	1·010	1·155	1·443	1·732
d_w (in.)	0·0114	0·0171	0·0228	0·0285	0·0342	0·0400	0·0456	0·0570	0·0684

AMERICAN NATIONAL—BEST-SIZE CYLINDERS

T.P.I.	80	72	64	56	48	44	40	36	32	28
d_w (mm)	0·183	0·203	0·229	0·262	0·305	0·333	0·366	0·406	0·457	0·523
d_w (in.)	0·0072	0·0080	0·0090	0·0103	0·0120	0·0131	0·0144	0·0160	0·0180	0·0206

AMERICAN NATIONAL—BEST-SIZE CYLINDERS—(*contd.*)

T.P.I.	27	24	20	18	16	14	13	12	11½	11
d_w (mm)	0·544	0·612	0·734	0·815	0·917	1·0698	1·128	1·222	1·275	1·334
d_w (in.)	0·0214	0·0241	0·0289	0·0321	0·0361	0·0412	0·0444	0·0481	0·0502	0·0525
T.P.I.	10	9	8	7½	7	6	5	4½	4	3½
d_w (mm)	1·466	1·631	1·834	1·956	2·095	2·443	2·934	3·259	3·665	4·191
d_w (in.)	0·0577	0·0642	0·0722	0·0770	0·0825	0·0962	0·1155	0·1283	0·1443	0·1650

Best sizes given by the Ex-Cell-O Corporation:
B.S.W. = 0·563691 P; American National = 0·5773505 P
B.A. = 0·5462624 P; International Metric = 0·5773505 P

Examples

(1) Whitworth screw, B.S.W., 1 in. major diameter, 8 t.p.i.; assume best size wire available. Calculate D_w.

Using formula, $D_w = D_o - 1{\cdot}6008\,P + 3{\cdot}1657\,d_w$
$= 1 - 0{\cdot}2001 + 0{\cdot}22318$
$= 1{\cdot}02308$ (to five dec. places)
$= 1{\cdot}0231$ in. (to nearest "tenth of a thou.")

Note that $P = \frac{1}{8}$ in. = 0·125 in. Best-size wire has diameter 0·0705 in. If the measured diameter over the wires is 1·0231 in. the screw is correct as regards effective diameter.

(2) U.S. National screw, 2-in. major diameter, 4½ t.p.i.; assume best-size wire available. Calculate D_w.

Using formula, $D_w = D_o - 1{\cdot}5155\,P + 3{\cdot}0000\,d_w$
$= 2 - 0{\cdot}33678 + 0{\cdot}3849$
$= 2{\cdot}04812$ in. (to five dec. places)

Best-size wire has diameter of 0·1283 (see Table). If the measurement over the wires is 2·0481 (measuring to nearest "tenth of a thou.") the effective diameter of the thread is correct.

APPLICATION OF THREE-WIRE SYSTEM TO METRIC THREADS

See Fig. 101.

Evidently $D_w = D_o + 2a$

$$\text{Also } a = \frac{3 \times d_w}{2} - 0{\cdot}75775\,P$$

EXAMPLE

Metric screw is 10 mm diameter and its pitch is 1·5 mm. Suppose the wire available has a diameter of 0·866 mm.

$a = (1\tfrac{1}{2} \times 0{\cdot}866) - (0{\cdot}75775 \times 1{\cdot}5)$
$1{\cdot}299 - 1{\cdot}1366 = 0{\cdot}1623$ mm
$D_w = D_o + 2a$
$= 10 + 0{\cdot}3246 = 10{\cdot}3246$ mm

Check by using Outside Diameter Formula (page 139).

$$\begin{aligned} D_w &= D_o - 1{\cdot}5155\,P + 3{\cdot}0000\,d_w \\ &= 10 - 2{\cdot}2733 + 2{\cdot}598 \\ &= 10{\cdot}3247 \text{ mm} \end{aligned}$$

Check by using Effective Diameter Formula (see below).

$$\begin{aligned} D_w &= D_e - 0{\cdot}866\,P + 3{\cdot}0000\,d_w \\ &= 9{\cdot}026 - 1{\cdot}299 + 2{\cdot}598 \\ &= 10{\cdot}325 \text{ mm} \end{aligned}$$

(Effective diameter is taken from table in B.S. 1095.)

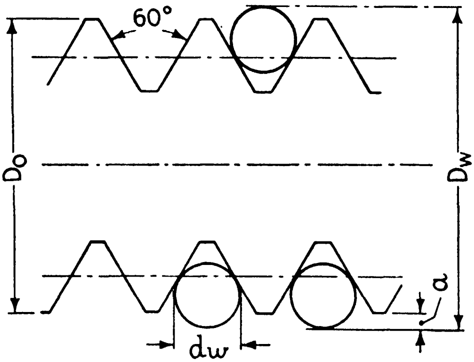


FIG. 101. THREE WIRES USED IN METRIC THREAD

FORMULAE BASED ON EFFECTIVE DIAMETER

Whitworth, $D_w = D_e - 0{\cdot}9605\,P + 3{\cdot}1657\,d_w$

U.S. National and Metric, $D_w = D_e - 0{\cdot}866\,P + 3{\cdot}0000\,d_w$

B.A., $D_w = D_e - 1{\cdot}1363\,P + 3{\cdot}4829\,d_w$

General Formula.

$$D_w = D_e - (A \times \text{pitch}) + (B \times \text{wire diameter}).$$

$$A = \tfrac{1}{2}\cot\theta \qquad B = \operatorname{cosec}\theta + 1$$

Where θ = half the thread angle.

Tables showing values of $0{\cdot}9605\,P$, $0{\cdot}866\,P$, etc., for threads of given pitches are given on page 141.

To calculate the effective diameter corresponding to a measured dimension over the wires the foregoing formulae are transposed, thus,

Whitworth, $D_e = D_w + (0{\cdot}9605\,P) - 3{\cdot}1657\,d_w$

U.S. National and Metric, $D_e = D_w + (0{\cdot}866\,P) - 3{\cdot}0000\,d_w$

B.A., $D_e = D_w + (1{\cdot}1363\,P) - 3{\cdot}4829\,d_w$

Generally, $D_e = D_w + (A \times \text{pitch}) - (B \times \text{wire diameter})$.

CAUTION. When using these and other formulae for finding diameters over wires it is important to see that all the terms in any one equation are in the same units, i.e. are all in inches or all in millimetres.

Alternative Method: Disregarding Helix Angle; Using Effective Diameter. To save time in the simplification of the last two terms in

the formulae for D_w given in preceding paragraphs, and to replace multiplication by addition and subtraction, the reader may refer to tabulated values of a dimension C. In Fig. 102 the dimension $\frac{1}{2}C$ is shown to be the measurement from the outside of the best-size cylinder to the pitch surface of the thread.

$$\text{Thus, } D_w = \text{pitch diameter} + C$$

$$\text{For a Whitworth thread } D_w = D_e - 0{\cdot}9605\,P + 3{\cdot}1657\,d_w.$$

$$\text{Taking } d_w = 0{\cdot}563691\,P, \text{ we get}$$

$$C = -0{\cdot}9605\,P + 3{\cdot}1657 \times 0{\cdot}563691\,P$$

This expression has been simplified for all the commonly used pitches employed in the various standard thread systems and the values of C tabulated. Here, for instance, is the tabulation of dimension C for commonly used pitches in the B.S.W. series. The table was supplied by the Ex-Cell-O Corporation.

TABLE FOR WHITWORTH THREAD

(See Fig. 102.)

$$D_w = D_e - 0{\cdot}960491\,P + 3{\cdot}1657\,W$$
$$= D_e + C$$

T.P.I.	PITCH (P)	PITCH LINE CONTACT MEASUREMENT	
		Wire Dia. d_w	Dimension C
48	0·0208 *33*	0·0117 *43*	0·0171 *65*
40	0·0250 *00*	0·0140 *92*	0·0205 *99*
36	0·0277 *78*	0·0156 *58*	0·0228 *88*
32	0·0312 *50*	0·0176 *15*	0·0257 *49*
28	0·0357 *14*	0·0201 *32*	0·0294 *28*
26	0·0384 *62*	0·0216 *81*	0·0316 *92*
24	0·0416 *67*	0·0234 *87*	0·0343 *32*
22	0·0454 *55*	0·0256 *22*	0·0374 *53*
20	0·0500 *00*	0·0281 *82*	0·0411 *95*
19	0·0526 *32*	0·0296 *68*	0·0433 *67*
18	0·0555 *56*	0·0313 *16*	0·0457 *76*
16	0·0625 *00*	0·0352 *31*	0·0514 *99*
14	0·0714 *28*	0·0402 *63*	0·0588 *54*
12	0·0833 *33*	0·0469 *74*	0·0686 *64*
11	0·0909 *09*	0·0512 *45*	0·0749 *07*
10	0·1000 *00*	0·0563 *69*	0·0823 *97*
9	0·1111 *11*	0·0626 *32*	0·0915 *52*
8	0·1250 *00*	0·0704 *61*	0·1029 *96*
7	0·1428 *57*	0·0805 *27*	0·1177 *10*
6	0·1666 *67*	0·0939 *49*	0·1373 *30*
5	0·2000 *00*	0·1127 *38*	0·1647 *95*
4½	0·2222 *22*	0·1252 *65*	0·1831 *06*
4	0·2500 *00*	0·1409 *23*	0·2059 *94*
3½	0·2857 *14*	0·1610 *54*	0·2354 *21*
3¼	0·3076 *92*	0·1734 *43*	0·2535 *30*
3	0·3333 *33*	0·1878 *97*	0·2746 *58*
2⅞	0·3478 *26*	0·1960 *66*	0·2865 *99*
2¾	0·3636 *36*	0·2049 *78*	0·2996 *27*
2⅝	0·3809 *52*	0·2147 *39*	0·3138 *95*
2½	0·4000 *00*	0·2254 *76*	0·3295 *89*

EXAMPLE

Whitworth screw 1 in. dia., ⅛ in. pitch. Effective dia. 0·9200 in. D_w = 0·9200 + 0·102996 = 1·022996 in. (say, 1·0230 in.). In 5-figure tables the effective dia. is given as 0·91996 in. If the latter value is used, D_w = 1·022956 in.

Examples

(1) Whitworth screw, B.S.W, 1 in. major diameter, 8 t.p.i.; assume best-size wire available.

Using formula,
$$D_w = D_e - 0{\cdot}9605\,P + 3{\cdot}1657\,d_w$$
$$= 0{\cdot}9200 - 0{\cdot}12006 + 0{\cdot}22318$$
$$= 1{\cdot}02312 \text{ (to 5 dec. places). Say } 1{\cdot}0231 \text{ in.}$$

In this calculation we have taken effective diameter (D_e) 0·9200 in. (basic size given in B.S. 84). It should be noticed that the coefficients

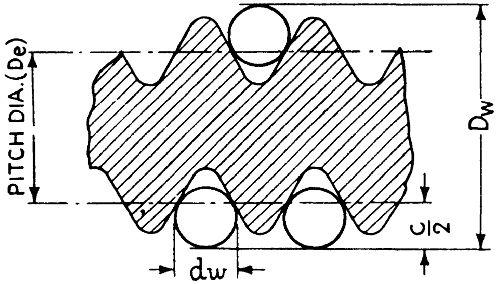


FIG. 102. WIRE MEASUREMENT OF WHITWORTH THREAD

See the Formula, $D_w = D_e + C$.
Pitch Diameter is another name for *Effective Diameter*.

of P and d_w are given to four decimal places in the formula. Thus the result, 1·0231 in., is probably "as near as matters," considering that no account has been taken of the obliquity of the thread.

(2) U.S. National screw (N.C.), 2 in. major diameter, 4½ t.p.i., assume best-size wire available.

Using formula,
$$D_w = D_e - 0{\cdot}866\,P + 3{\cdot}0000\,d_w$$
$$= 1{\cdot}8557 - 0{\cdot}1924 + 0{\cdot}3849$$
$$= 2{\cdot}0482 \text{ in.}$$

If it is desired to work to more than four decimal places the coefficient of P can be taken as 0·866025. The actual depth of a U.S. thread can be taken as 0·649519 × pitch, and the effective diameter can be found by subtracting the single depth of thread from the major diameter.

(3) B.A. screw, No. 0; wire available is 0·530 mm diameter.

From tables the major diameter is 6·0 mm, pitch 1 mm.

Using formula,
$$D_w = D_e - 1{\cdot}1363\,P + 3{\cdot}4829\,d_w$$
$$= 5{\cdot}4 - 1{\cdot}1363 + 1{\cdot}846$$
$$= 6{\cdot}11 \text{ mm.}$$

TAKING HELIX ANGLE INTO ACCOUNT. The formulae given up to the present apply strictly to "threads" with zero helix angles, i.e. to parallel annular grooves. Taking the general run of standard and near-standard vee threads, variations in the helix angle have

slight effect on the wire diameter, and it is economical and convenient in practice to employ one wire diameter per given pitch—irrespective of the helix angle. In subsequent paragraphs formulae are given which take into account the obliquity of the wires in the thread grooves.

The reason why the measurement over the wires is affected by the helix angle is that contact between the wire and the workpart is not normal to the axis, as it should be. Instead, it is normal to the helix, engaging the thread form at a reduced distance and a reduced angle of contact. This would still apply if balls were substituted for wires.

$$\text{Effective diameter } (D_e) = D_w + \frac{P}{2\tan\frac{\alpha}{2}} - d_w - \frac{d_w}{\sin\frac{\alpha}{2}} - c$$

This formula can be transposed as follows—

$$D_w = D_e - [\tfrac{1}{2} P \operatorname{cotan} \theta - (\operatorname{cosec} \theta - 1)\, d_w] + 2\, d_w - c$$

where c is a correction factor for compensating the obliquity of the wires in the thread grooves, d_w is wire diameter, and α is *total* thread angle, $\theta = \frac{1}{2}\alpha$.

For such accurate readings special charts and tables have been prepared by the Société Genevoise d'Instruments et Physique, Geneva. For those who wish to study the mathematical formulae and charts used in the wire measurement of threads, reference is recommended to an informative article in *Machinery*, 20th October, 1938.

In *Notes on Screw Gauges* will be found formulae for calculating the effective diameters of threads of different systems, taking into account a factor c, a correction due to the tilting of the cylinders on account of rake. The formula given is $E = T + P - c$, all terms in which, apart from c, are readily calculated by substitution, the value of c being found by reference to nomograms supplied in the *Notes*.

Earle Buckingham Formula

This includes the effect of the helix angle on the seating in the thread grooves of pins or needles of special diameters, these diameters being calculated from a formula or taken from tables. Formulae which take helix angle into account are definitely essential when measuring multi-start screws, worms, etc., with relatively large leads, but in general are not so essential when measuring most single-start threads. The application of the Buckingham formula to thread measurement is explained at length in *Machinery's Handbook*, which also contains the necessary tables.

Formulae Recommended by Ex-Cell-O Corporation for Threads with Helix Angles above 10°

These allow for the change in width of contact due to the helix angle, but do *not* allow for the reduction in angle, nor for the reduction in effective diameter at the point of contact, due to the curvature on the workpiece. The formulae given below are identical with those used by the Ex-Cell-O Corporation, except for the alteration of letter symbols to agree with those used throughout this chapter.

$$d_w = A\,\frac{\cos\text{ (Helix angle of thread on effective diameter)}}{\cos\text{ (Half angle on thread form in axial plane to work)}}.$$

$$D_w = \text{Pitch dia.} + d_w\,(1 + \sin F)$$

where d_w = Best-size wire, for pitch-line contact.
F = Half angle on thread form in axial plane to work.
A = Width of thread form in axial plane at pitch diameter.

"Suitable wires of diameter d_w should be made, as otherwise the use of any available 'next wire diameter' involves considerable calculations due to a change of the helix angle at the point of engagement."

ALTERNATIVE METHOD. EFFECTIVE DIAMETER MEASUREMENT. By this method, fully described in *Notes on Screw Gauges*, and readily applied when the inspector has access to a *diameter-measuring machine*, measurements are made (or readings are taken) without reference to the zero setting of the micrometer. The following are step-by-step hints on the procedure—

(1) Select a *standard cylinder* or *cylindrical reference disc* as near the size of screw to be measured as possible, and a pair of thread-measuring cylinders appropriate to the pitch of the thread.

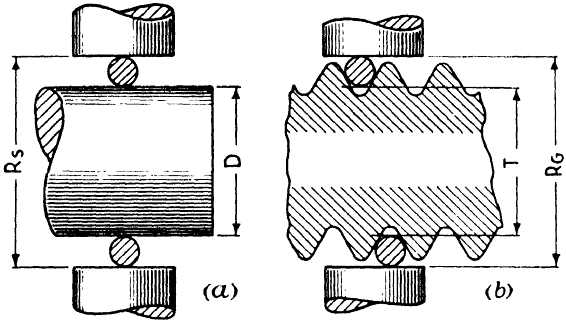


FIG. 103. ILLUSTRATING ALTERNATIVE METHOD OF EFFECTIVE DIAMETER MEASUREMENT

(2) Place the standard cylinder (dia. D) between the centres of the measuring machine with one of the thread-measuring cylinders suspended on either side of it, as shown in Fig. 103 (a). Take a micrometer reading over the small cylinders. Call this R_S. (R is the symbol usually employed in descriptions of this method.)

(3) Remove the standard cylinder and replace it by the screw gauge to be measured, as shown in Fig. 103 (b). Take a second micrometer reading over the cylinders. Call this R_G.

From the readings thus taken we can find a value T, which is the dimension underneath the cylinders. This is the formula—

$$T = D + R_G - R$$

Then with the following formula the effective diameter (D_e) of the screw can be calculated—

$$D_e = T + P - c$$

where T = measured distance underneath the cylinders
P = a constant shown on the certificate supplied by the N.P.L.
c = a correction factor, small in quantity, depending mainly upon the helix angle of the screw and corresponding "tilt" or "swivel" of the cylinders.

Notes on the Value of "c." It is approximately 0·00015 in. for B.S.W. threads (when best-size cylinders are used), 0·0001 in. for

B.S.F. and B.S.P. threads, and 0·00006 in. for B.A. threads. The exact values of c for the above-mentioned screw forms and for others having similar helix angles are obtainable from the nomograms in *Notes on Screw Gauges.* For single-start screws having a relatively coarse pitch in relation to diameter the value of c increases and can be found approximately from one of the following formulae—

For Whitworth threads, 55°, $c = 0{\cdot}086 \dfrac{p^2 d}{(T + d)^2}$

For S.I. and U.S. threads, 60°, $c = 0{\cdot}076 \dfrac{p^2 d}{(T + d)^2}$

For Single-start Acme threads, 29°, $c = 0{\cdot}190 \dfrac{p^2 d}{(T + d)^2}$

where p = pitch of thread, d = mean diameter of measuring cylinder used.

If the value of c, as calculated from the above formulae, exceeds 0·001 in., and also for all multi-start threads, more exact formulae should be used for calculating c. These will be found in *Notes on Screw Gauges.*

Notes on the Value of "P." As stated previously, P is a constant shown on the Certificate of Examination issued by the N.P.L. Its value depends on the pitch and angle of the screw, and the mean diameter of the small cylinders used.

If D_e = required effective diameter
T = measured dimension under cylinders
p = pitch of thread
d_w = mean diameter of cylinders used
θ = semi-angle of thread
c = correction factor (previously explained).

$$D_e = T + P - c$$

$$\text{where } P = \tfrac{1}{2}p \cot \theta - (\operatorname{cosec} \theta - 1)\, d$$

Values of θ: Whitworth $27\tfrac{1}{2}°$; B.A. $23\tfrac{3}{4}°$; S.I., U.S., C.E.I. 30°.

For Whitworth threads: $P = 0{\cdot}96049\, p - 1{\cdot}16568\, d_w$
For B.A. threads: $P = 1{\cdot}13634\, p - 1{\cdot}48295\, d_w$
For 60° threads: $P = 0{\cdot}86602\, p - d_w$

EXTRACTS FROM TYPICAL N.P.L. "CERTIFICATE OF EXAMINATION"

Cylinder No.	Mean Diameter at 68° F. Inches	Pitch and Form of Screw	Values of P, Inches
12677 C. N.P.L.	0·008 52		
12731 C. N.P.L.	0·008 52	No. 9 B.A.	0·004 8
12752 C. N.P.L.	0·008 52		

Cylinders specially manufactured to standard form are obtainable from a number of firms, e.g. Messrs J. E. Baty & Co., Ltd., Victoria Street, London, S.W.1. In Fig. 104 is shown a typical cylinder made of special steel, hardened, ground and lapped to great accuracy. These cylinders can be supplied with a *Certificate of Examination* giving, to five decimal parts of an inch, the mean diameter, together with a P value used in calculating effective diameter. The cylindrical portion "A" is used for measuring purposes. In the larger diagram the step between "C" and "A," and between "A" and "B" has been exaggerated.

SUMMARY—EFFECTIVE DIAMETER

1. If the effective diameter of a screwed plug is less than its nominal

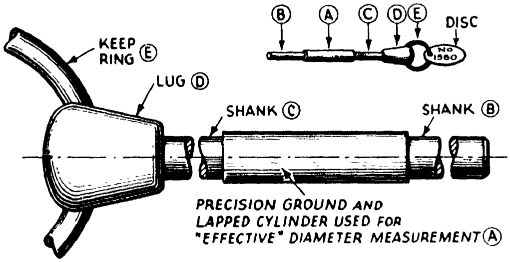


FIG. 104. MEASURING CYLINDER

value, the threads are thin; and if greater the threads are thick. The reverse is the case for a ring.

2. In a perfect thread, having its angles, crests and roots accurate and symmetrical, and its flanks straight, the simple effective diameter equals the mean of its major and minor diameters. It also equals the major diameter minus the single depth of thread. Thus:

$$\text{Effective diameter} = \tfrac{1}{2}\,(\text{major diameter} + \text{minor diameter})$$
$$= \text{major diameter} - \text{single thread depth}$$

MEASURING THREAD ANGLES. Thread angles and radii are usually inspected on some form of projector or toolmaker's microscope. Some of these microscopes have a graticule marked with an outline of a perfectly-shaped thread. Particulars of toolmakers' microscopes specially suitable for the *measurement* of thread angles are obtainable from Optical Measuring Tools, Ltd., Slough, Bucks.

Using Three Wires. The three-wire system is employed, using two sets of wires of different diameter, so that wires touch the flanks of the threads at different distances (as widely separated as possible) from the axis. Obviously if the wire is too small it will rest on the valley radius; if too large it will rest on the radii of the crests. For B.S.W. threads we may reiterate the limiting diameters of the wires. They are as follows—

$$\text{Smallest wire diameter} = 0{\cdot}506 \times P$$
$$\text{Largest wire diameter} = 0{\cdot}853 \times P$$

If the screw is correct,

$$D_w = D_e + d_w (1 + \operatorname{cosec} \alpha/2) - \tfrac{1}{2} P \cot \alpha/2$$

where α = thread angle (55° on Whitworth threads).

See alternative formula given at the end of the following example.

EXAMPLE.

Suppose we have to check the effective diameter of a screw plug, 1 in. diameter, B.S.W., 8 t.p.i.

In general we aim at using cylinders which make pitch-line contact, i.e. the *best-size cylinders.* If these are not available we endeavour to find cylinders which make contact inside the middle fifth of the straight parts of the flanks. Employing this method,

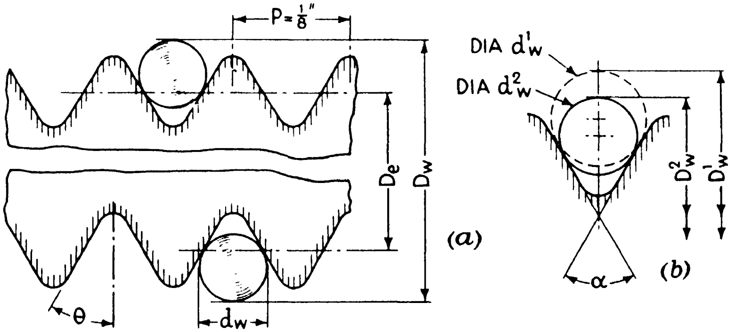


FIG. 105. CHECKING EFFECTIVE DIAMETER AND THREAD ANGLE

$$\text{Max. dia.} = \frac{0{\cdot}853}{8} = 0{\cdot}1066 \text{ in. dia.}$$

$$\text{Min. dia.} = \frac{0{\cdot}506}{8} = 0{\cdot}0632 \text{ in. dia.}$$

$$\text{Mean dia.} = \frac{0{\cdot}564}{8} = 0{\cdot}0705 \text{ in. dia. (best-size).}$$

The dimensions *over* the cylinders, D_w, in Fig. 105 (*a*) can be calculated as follows—

$$\begin{aligned} D_w &= D_e - [\tfrac{1}{2} P \operatorname{cotan} \theta - (\operatorname{cosec} \theta - 1)\, d_w] + 2\, d_w - c \\ &= 0{\cdot}9200 - [\tfrac{1}{2} \cdot \tfrac{1}{8} \cdot \operatorname{cotan} 27\tfrac{1}{2}^\circ - (\operatorname{cosec} 27\tfrac{1}{2}^\circ - 1)\ 0{\cdot}0705] \\ &\qquad + 2(0{\cdot}0705) - 0{\cdot}00012 \\ &= 1{\cdot}022999 \text{ in. (say, } 1{\cdot}0230 \text{ in.)} \end{aligned}$$

NOTE

$\theta = \tfrac{1}{2}$ thread angle; $D_e = 0{\cdot}9200$ from tables; $c = 0{\cdot}00012$ from nomogram in *Notes on Screw Gauges*; cotan $27\tfrac{1}{2}^\circ = 1{\cdot}9209821$; cosec $27\tfrac{1}{2}^\circ = 2{\cdot}1656806$.

If equipment is available, the screw can be measured on a thread diameter-measuring machine of floating carriage type, using a maximum pressure of, say, six ozs. If the machine is used, only two cylinders or wires are required.

EXAMPLES

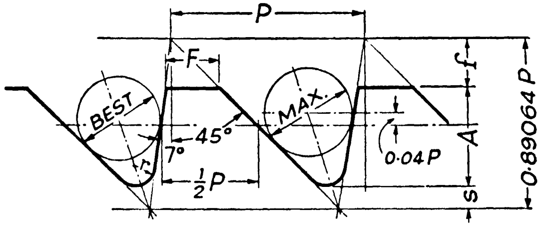
(1) Suppose that to measure the same Whitworth screw as in the previous example wires of 0·1 in. diameter are used. Calculate the dimension over the wires. (ANSWER: 1·1165 in.)

(2) Calculate the dimension over the wires if their diameter is 0·0686 in. (ANSWER: 1·0171 in.)

The form of the thread is best checked on a projector by meshing its image with a standard thread-form diagram. If this is not available the thread angle can be measured by using two different pairs of rollers. See Fig. 105 (*b*). A formula often recommended for this purpose is—

$$\text{Sin } \tfrac{1}{2} \text{ thread angle} = \frac{d^1_w - d^2_w}{(D^2_w - D^1_w) - (d^1_w - d^2_w)}$$

This formula applies to all threads, regardless of angle. The theory



$r = 0{\cdot}12055P \quad A = 0{\cdot}50586P \quad s = 0{\cdot}13946P$

$F = 0{\cdot}27544P \quad f = 0{\cdot}24532P$

FIG. 106. BUTTRESS THREAD OF 7°/45° FORM

underlying the method is similar to that employed in measuring tapered holes by means of two balls.

EXAMPLE

Suppose that when using wires of 0·1 in. dia. (d^1_w) the reading over the wires is 1·1162 in. (D^1_w) and that when using wires of 0·0686 in. dia. (d^2_w) the reading over the wires is 1·0174 in. (D^2_w). Use the formula to calculate the thread angle.

$$\frac{0{\cdot}0314}{(1{\cdot}1162 - 1{\cdot}0174) - 0{\cdot}0314} = \frac{0{\cdot}0314}{0{\cdot}0988 - 0{\cdot}0314}$$

$$= \frac{0{\cdot}0314}{0{\cdot}0674} = 0{\cdot}4658 = \sin^{-1} 27^\circ\ 46'$$

Thus, whole-thread angle $= 2 \times 27^\circ\ 46' = 55^\circ\ 32'$.

BUTTRESS THREADS. Measurement by Wires. See Fig. 106. The best wire diameter for a 7°/45° buttress thread is 0·43766*P*; the maximum diameter is 0·47697*P*. The best size cylinder contacts the pressure flank of the thread at the pitch line.

ACME THREADS. The following proportions relate to the American National Acme thread and are those in general use. The section is shown in Fig. 107, the basic proportions being as follows—

H = Basic depth of thread = $\frac{1}{2} P$

NOTE: A clearance of at least 0·010 in. is added to the basic thread depth on threads of 10 pitch and coarser, or 0·005 in. on threads with finer pitches, thus producing extra depth. Hence the commonly given rules:

$H = \frac{1}{2} P + 0{\cdot}01$ in. and
$H = \frac{1}{2} P + 0{\cdot}005$ in.

$F = 0{\cdot}37069\, P$
$R = 0{\cdot}37069\, P - (0{\cdot}52 \times \text{clearance})$
Thread angle = 29°
(Proportions given in *U.S. Handbook of Screw Thread Standards*—1942 edition. See also B.S. 1104—1942.)

Wire Measurement. It is pointed out in U.S. National Bureau of Standards Handbook, No. H28, that to determine the quality of fit of Acme threads we can refer either to (1) the pitch diameter or (2) the thread thickness in relation to basic major diameter (that is, the thread thickness at the nominal pitch diameter). In both cases the tests can be made by using three wires. In the case of the Acme thread the thread angle is small and its cotangent large, so that the helix angle ought to be taken into account when obtaining values of either pitch diameter or thread thickness.

The following formula for Acme thread measurement has been derived from a general formula which takes the helix angle into account.

$$D_e = D_w + \frac{1{\cdot}93336}{n} - d_w\,(4{\cdot}99393 + 1{\cdot}87178\, S^2)$$

Where n = number of threads per inch
S = tangent of helix angle.

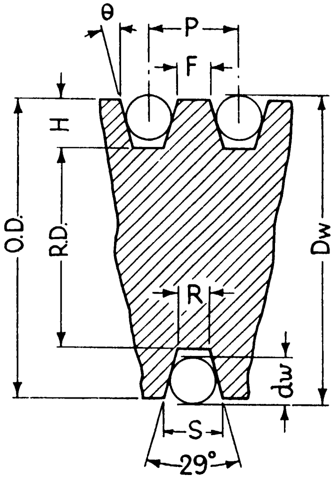


FIG. 107. ACME THREAD

$O.D.$ = Outside Dia. of Screw.
P = Pitch.
d_w = Wire Diameter.
H = Basic Thread Depth = ½ Pitch.
R = Width of Root.
F = Width of Crest.
$R.D.$ = Root Diameter.
D_w = Measurement Over Wires.
S = Space at Crest.
θ = Pressure Angle = 14½°.

$$\text{For most purposes } S = \frac{1}{\pi \times \text{No. of t.p.i.} \times \text{nominal pitch dia.}}$$

$$\text{or} = \frac{\text{lead}}{\pi \times \text{nominal pitch dia.}}$$

according to whether the thread is multi-start or single-start. The substitution of nominal pitch diameter in the above formulae is satisfactory except in the case of multi-start threads having very large helix angles. In such cases there is a relatively large difference between the nominal and measured pitch diameters.

To determine thread thickness at the nominal pitch diameter it is possible to take readings over three wires. Thread thickness can be calculated thus—

$$t = 1{\cdot}12931\ P + 0{\cdot}25862\ (D_w - D_o) - d_w\ (1{\cdot}29152 + 0{\cdot}48407\ S^2)$$

where t = thread thickness at a depth B, which equals $P/4$
P = pitch
D_w = dimension over the wires
D_o = major diameter of the thread
d_w = diameter of the wires
S = tangent of the helix angle at pitch line.

One-wire Method. The wire measurement of Acme threads is discussed at some length in *Machinery's Handbook*, where the method is mentioned of checking Acme threads of small pitch and small helix angle by placing a wire of suitable diameter in the thread space. If the wire diameter = 0·48725 × pitch, the top of the wire should come flush with the tops of the threads. In applying this method one ignores the helix angle and assumes (1) that the threads have straight sides if cut by a plane passing through the axis of the screw, (2) that the basic thread thickness at the pitch line is equal to one-half the pitch.

MAXIMUM, MINIMUM AND BEST-SIZE WIRES—ACME THREADS
(All diameters in inch units)

T.P.I.	2	2½	3	3½	4	5	6	8	10	12
Max.	0·3250	0·2600	0·2167	0·1857	0·1625	0·1300	0·1083	0·0813	0·0650	0·0542
Min.	0·2436	0·1949	0·1624	0·1391	0·1218	0·0975	0·0812	0·0609	0·0487	0·0406
Best	0·2582	0·2066	0·1722	0·1476	0·1291	0·1033	0·0861	0·0646	0·0516	0·0430

PRACTICAL NOTES ON THE USE OF WIRES OR CYLINDERS

The working surfaces of the wires should be very hard and highly polished. They must, of course, be made precisely as to size; some authorities stating that they should be cylindrical to within 0·00003 in. over their working surfaces and parallel to within, say, 0·00005 in. If we are to measure the pitch diameter of a gauge to an accuracy of 0·0001 in. it is evident that we must know the wire diameters to, say, 0·00002 in. If the diameters of the wires are known only to an accuracy of 0·0001 in. it is unwise to expect an accuracy better than 0·0003 in. in the measurement of pitch diameter. Hence the need for accurately made wires and the common use of thread-measuring machines which read accurately to 0·00001 in.

Whilst with careful handling the squareness of the micrometer to the axis of the screw being measured is tolerably certain when three wires are used, it is quite certain if some form of "floating micrometer" is employed. This ensures that the spindle of the micrometer is always at right-angles to the axis of the screw. A "floating micrometer"

machine for measuring screw gauges was designed at the National Physical Laboratory and machines of this type, called *diameter-measuring machines*, are obtainable commercially. See Figs. 93 and 94. They enable the effective diameters of screws to be measured by using cylinders, pins or wires, and the minor diameters by using vee-pieces or core prisms. The wires and prisms are suspended from supports fixed on the top or floating carriage, so that they may be applied to the screw as shown in Fig. 94. When using an ordinary micrometer it is essential to use three wires to ensure squareness, but only two need be used if a diameter-measuring machine is available.

Pressure must be regulated when measuring over wires. Every cylinder makes "point contacts" with flanks of the screw. Furthermore, there is a wedging effect between each cylinder and the mating flanks. Thus, unless very slight measuring pressures are applied there is bound to be an appreciable amount of elastic deformation. This has been the subject of research at the N.P.L. and a nomogram for computing the compression correction is given in *Notes on Screw Gauges.* The Brown & Sharpe Co. recommend that for pitches finer than 20 threads per inch a pressure of 1 lb be used. For pitches of 20 threads per inch and coarser their recommendation is up to 2½ lb. On modern diameter-measuring machines there is entire elimination of the personal "feel" of the micrometer, and measuring pressure is controlled. The adjustable anvil is fitted with a fiducial indicator which operates under a pressure of about 8 oz, or less if required.

Use of Sewing Needles. For a large number of screws in general use ordinary sewing needles serve admirably for effective diameter measurement. The following table gives the designating numbers usually printed on the outsides of the packets, and also gives the corresponding diameters. Of course, careful checking of these diameters and selection of needles is essential. Lapping may be necessary. Sewing needles are cheap and if several packets are obtained and their contents carefully examined, it will generally result in obtaining at least one set having about ⅓ to ½ their lengths parallel and of uniform diameter between very close limits. Means of dependable measurement to a "tenth of a thou." must be available.

SEWING NEEDLES—NOMINAL DIAMETERS

No. of Packet	Needle Dia.	No. of Packet	Needle Dia.	No. of Packet	Needle Dia.	No. of Packet	Needle Dia.
2/0	0·055	2	0·042	5	0·033	8	0·023
1/0	0·049	3	0·038	6	0·029	9	0·020
						10	0·017
1	0·047	4	0·036	7	0·026	11	0·015

Use of Twist Drills, etc. Shanks of twist drills are sometimes used as measuring cylinders. Some of these shanks are soft and may require

hardening. It is useful to refer to a table of letter and number sizes of Morse twist drills. Rods of silver steel and lengths of music wire are sometimes used. In various engineering pocket books tables are given showing silver-steel numbers (according to Stubbs's Wire Gauge System) with corresponding diameters in decimals of an inch, also equivalent diameters, in decimals of an inch, to music-wire numbers.

FIG. 108. FOUR STEPS IN USING THE O-VEE GAUGE TO MEASURE THE EFFECTIVE DIAMETER OF A SCREW, ½ IN. DIA., B.S.F., MEDIUM FIT

The O-Vee Gauge. This gauge is convenient for the accurate measurement of effective diameter of the smaller screw threads. A glance at the illustrations in Fig. 108 will show that the design is based on the three-wire system. Each gauge is fitted with a data plate on which is engraved the high and low limits over the wires for any specified fit. They are supplied by Hamber Eng. Co., Ltd., for right- and left-hand threads, most thread forms and a large range of pitches. These are the steps when using the gauge: (1) depress the lever fully, (2) insert screw and release the lever, (3) measure over the wires, (4) compare the reading with the figures on the plate.

In all such measurement the personal "feel" of the inspector has to be considered, for some screw the micrometer more tightly upon the workpiece than others. It is a good plan for an inspector to measure a plain reference disc or plug gauge of known diameter in the first instance and then, with the knowledge so gained, use the same micrometer with the same pressure on the screw and wires.

Thread-measuring Parallels. The tyro in thread measurement soon finds that it is not always easy to arrange for the support of the workpart simultaneously with the adjustment of the micrometer and the location of three wires in the thread grooves. All these items together make an awkward collection for one pair of hands. In the absence of a thread-measuring machine various improvised methods are employed to facilitate the measuring process, e.g. the wires may be pressed into the thread grooves and held by a lump of plasticine or wax at each end. In another arrangement the micrometer is fitted with two attachments or frames, one of which

carries one wire whilst the other carries two. These frames, being free to rotate on the micrometer parts, are able to align themselves to the helix angles of the threads.

Not only can the three-wire system be awkward to employ unless

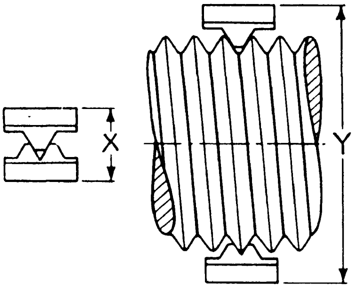


FIG. 109. THE TWO ESSENTIAL DIMENSIONS WHEN THREAD-MEASURING PARALLELS ARE USED. $D_e = Y - X$.

thoughtful preparation is made, but it can also prove expensive if an extensive set of best-size wires is considered necessary.

These are some reasons why Marlco Thread-measuring Parallels

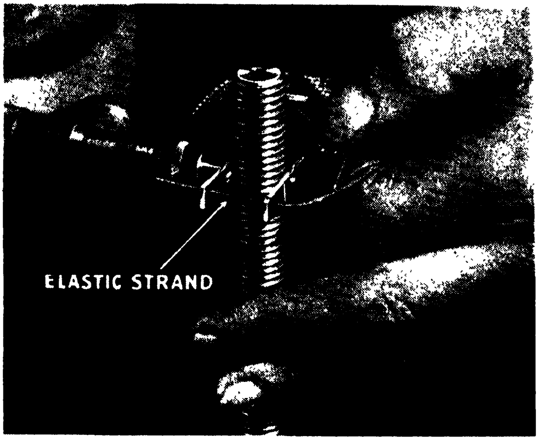


FIG. 110. MEASURING ⅝ IN. WHIT. SCREW WITH MARLCO THREAD-MEASURING PARALLELS

(*Courtesy of Messrs. W. H. Marley & Co., Ltd.*)

are preferred by many inspectors for effective diameter measurement. In the line diagram, Fig. 109, the similarity of these parallels to thread micrometers is obvious at a glance, but whilst the wedge and vee principle is common to both methods, the linear contact of the thread micrometer is replaced in the parallels by gauging surfaces of 0·5 in., so that they retain their accuracy longer. The versatility of these parallels can be gauged from the fact that one pair of them can be

used for all threads from 8 to 13 t.p.i. Whitworth, of any diameter and of either hand, in conjunction with micrometers, verniers, comparators, etc. The only mathematics involved is the subtraction of the

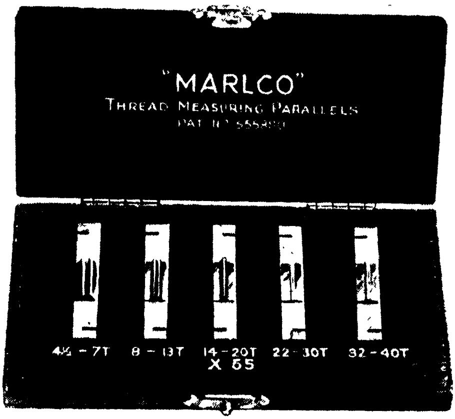


FIG. 111. A TYPICAL SET OF PARALLELS FOR CHECKING ANY THREADS OF WHITWORTH FORM FROM 4½ TO 40 T.P.I.

dimension X from the dimension Y shown in Fig. 109. To support the parallels during the process of measurement, an elastic strand is used to form a linkage, this being threaded through the slots in the parallels before or after they are placed in contact with the threads to be measured.

CHAPTER XVI

TERMS AND DEFINITIONS RELATING TO SCREW THREADS, WORMS, AND HOBS, WITH USEFUL EXPLANATORY NOTES

In this chapter will be found a number of terms relating to screw threads, worms, and hobs, together with full explanation and useful formulae.

SCREW THREADS

General

Screw Thread. A single-start thread is the helical ridge produced by forming a continuous helical groove of uniform section in the material of a cylinder or cone. If the thread winds around a cylinder it is known as a *parallel screw thread.* If it winds around a cone it is known as a *tapered screw thread.*

Multiple-start Screw Thread, or multi-start thread. This is produced by forming on a cylinder or cone (most commonly a cylinder) two or more helical grooves, equally spaced and similarly formed in an axial section. Multi-start threads give a "quick traverse" without sacrificing core strength. See Fig. 112.

Number of Starts is the number of grooves or thread sections in a plane at right angles to the axis of the thread. It is equal to the lead divided by the pitch.

External Thread. The thread formed on the *outside* of a workpiece, as on a common bolt or stud.

Internal Thread. The thread formed on the *inside* of a workpiece, as in a nut or female screw gauge.

Hand. See definition of *hand* on page 173.

Axis of Thread is the imaginary line running longitudinally through the centre of the screw, worm, or hob, and from which all corresponding parts are equi-distant.

Butt End. The end of the thread from which the ragged end or feather edge has been removed in order that the thread may finish abruptly with its complete or entire cross-section. This avoids end-thread breaking. It also avoids tearing or marking of the mating thread during assembling or dismantling. The operation of removing the ragged end is sometimes called **end threading.** See Fig. 113.

Dirt Groove. A groove cut axially along a screw plug or ring gauge to allow dirt and other foreign matter to escape when the gauge is assembled with the product. The depth of the groove should be slightly more than the depth of thread, say, 0·01 in., and about equal in width to the pitch of the thread. Sharp edges should be rounded off

to avoid any cutting or tearing action and any "rag" edge thrown into the thread spaces should be removed preferably with a wire brush.

Interrupted Thread. A term sometimes applied to screwing taps having alternate threads removed from one or more of the flutes.

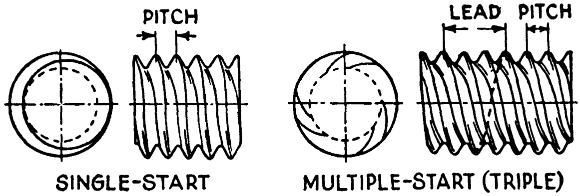


Fig. 112. Conventional Views of Single-start and Multi-start Vee Threads

Depth of Engagement. The depth of engagement between two mating screw threads is the distance, measured radially, by which their thread forms overlap each other. See Fig. 114.

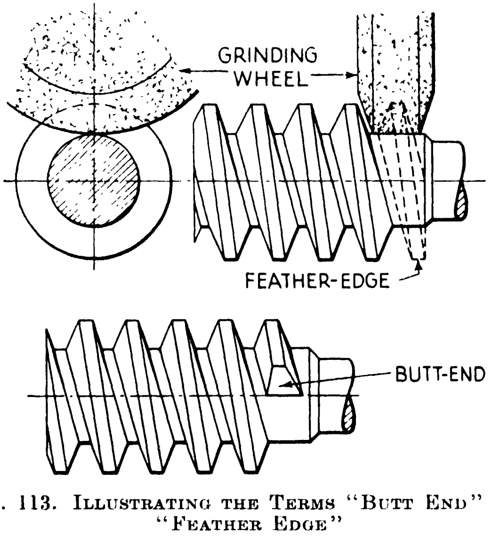


Fig. 113. Illustrating the Terms "Butt End" and "Feather Edge"

Length of Engagement. This is the length, measured parallel to the axis, over which two mating threaded pieces make contact. See Fig. 114.

Form and Proportions

Form of Thread. This is the shape of the contour of one complete thread as seen in axial section.

Crest of Thread. This is defined as the prominent part of a thread, whether it be external or internal.

Root of Thread. This is defined as the bottom of the groove between the two flanks of the thread, whether it be external or internal.

Flanks of Thread. These are the straight sides which connect the crest with the root.

Angle of Thread, or Thread Angle. This is the angle between the flanks or slopes measured in an axial plane.

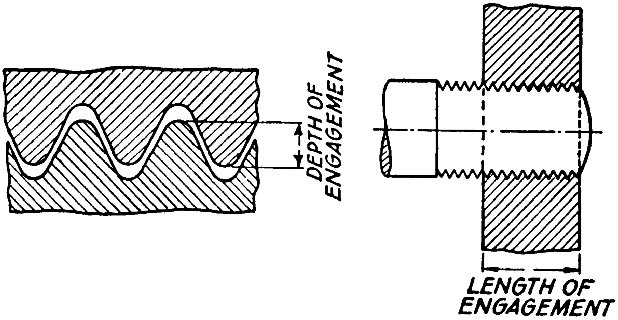


FIG. 114. ILLUSTRATING DEPTH AND LENGTH OF ENGAGEMENT

NOTES

Whereas on threads other than worms and hobs the flank angle is measured in a plane which contains the axis of the screw, on worms and hobs conforming

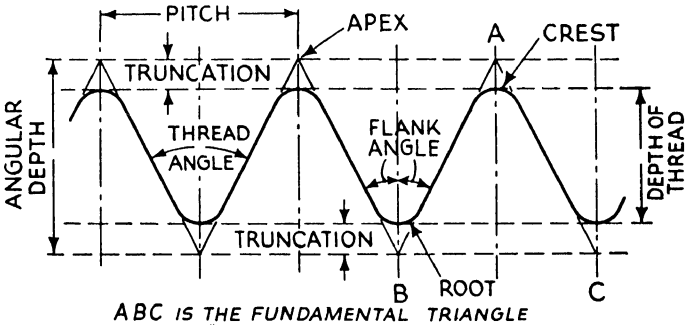


FIG. 115. ILLUSTRATING THREAD TERMS

to B.S. recommendations the flank angle is measured in a plane normal to the pitch diameter helix. It is then more properly referred to as the normal pressure angle.

On most screw threads the flank angles are equal. For instance, on the B.S.W. thread each angle is 27° 30′. A typical exception is a common form of buttress thread on which one flank angle is 45° whilst the other is 5°.

Flank Angles. These are the two angles between individual flanks and the perpendicular to the axis which passes through the vertex of the fundamental triangle. See Fig. 116.

Pitch (P). Pitch is the distance, measured parallel to the axis of the thread, between corresponding thread forms in the same axial plane.

On many drawings of thread sections it is found convenient to show pitch as the distance from the centre of one thread crest to the centre of the next. This is correct whether the thread be single-start or multi-start. On single-start threads,

$$\text{Pitch} = \frac{1}{\text{No. of threads per inch}}$$

On multi-start threads,

$$\text{Pitch} = \frac{\text{lead}}{\text{No. of threads or starts}}$$

Lead (L). The axial distance a screw advances axially for one revolution.

NOTES

Thus if a bolt be held securely and its nut rotated once completely it will travel along the bolt a distance known as the lead. On single-start threads pitch and lead are identical. On a double-start thread the lead is twice the pitch. On a treble-start thread the lead is three times the pitch, and so on.

$$\text{Lead} = \text{pitch} \times \text{No. of threads or starts.}$$

Axial Thickness of the thread is the distance between opposite faces of the same thread measured on the pitch cylinder in a direction parallel to the axis of the thread.

NOTES

On vee-threads of correct standard dimensions the axial thickness is equal to one-half of the axial pitch. A "thick thread" is greater than one-half of the axial pitch in its axial thickness; conversely a "thin thread" is less. As the measurement of axial thickness is made on the pitch cylinder it follows that this particular thickness is measured at mid-depth of the thread on threads having standard depths and symmetrical forms. On thread-forming tools, e.g. cutters, hobs, taps, etc., the axial thickness is sometimes made greater, or less, than one-half the axial pitch in order to meet special requirements. Thus it is customary when cutting threads which are subsequently to be metal-plated or lacquered to cut them with a reduced axial thickness (i.e. an axial thickness less than the nominal thickness obtained by halving axial pitch). This allows for the deposit of plating. If the deposit is to be 0·0005 in. in thickness the thread would be cut 0·001 in. less than nominal thickness, so as to obtain a plated thread having an axial thickness equal to one-half of the axial pitch.

Depth of Thread is the distance from the crest, or "tip" of the thread to the root of the thread measured perpendicular to the longitudinal axis.

NOTES

With few exceptions, of which the Sharp-Vee thread is an example, the *depth* of thread is less than the *angular depth*, i.e. the depth of the fundamental triangle —caused by rounding off the apex, as in threads with a controlled radius, e.g. B.S.W., B.A., etc., or by truncating the triangle to give a desired width of flat as in U.S. National and Metric screw threads.

The following constants may be used to calculate the depth of various threads. Note that D represents depth of thread and P represents pitch.

Acme thread	$D = 0{\cdot}5\,P$
American National thread	$D = 0{\cdot}649519\,P$
B.A. thread	$D = 0{\cdot}6\,P$
B.S. cycle thread	$D = 0{\cdot}5327\,P$

B.S. conduit thread	$D = 0{\cdot}640327\,P$
B.S. pipe thread	$D = 0{\cdot}640327\,P$
B.S. Whitworth thread	$D = 0{\cdot}640327\,P$
Buttress thread (form varies)	$D = 0{\cdot}69\,P$ to $0{\cdot}75\,P$
Metric thread (form varies)	$D = 0{\cdot}6855\,P$ to $0{\cdot}7035\,P$
Sharp-Vee thread	$D = 0{\cdot}86603\,P$
Square thread	$D = 0{\cdot}5\,P$

Fundamental Triangle. The fundamental triangle of a V-thread is shown in Fig. 115. It is lettered ABC and is formed by extending the flanks and joining points B and C. Note that BC = pitch and that the vertical height of the triangle is sometimes called the *angular depth* or the *theoretical depth*. The point A is the *apex* of the triangle ABC.

Truncation. A thread may be truncated at the crest, at the root, or at both crest and root. The truncation at the crest is the radial distance from the crest to the nearest apex of the fundamental triangle. Similarly the truncation at the root is the radial distance from the root to the nearest apex. See Fig. 115.

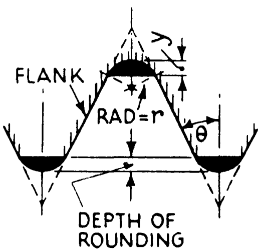


FIG. 116. DEPTH OF ROUNDING

Depth of Rounding. Whilst this term is not included in B.S. 84—1940 it is used in various well-known handbooks in the following sense. See dimension y in Fig. 116. It is the distance, measured radially, from the crest of the thread to the point of tangency between the crest radius and the flank. There is a similar depth of rounding at the root.

$$y = r - r \operatorname{Sin} \theta$$

where y = depth of rounding,
r = radius of crest or root,
θ = flank angle or half the thread angle.

The depth of rounding on a Whitworth thread is $0{\cdot}07392\,P$. Many Whitworth threads (especially internal threads) are now made of *truncated form*, i.e. they are reduced in diameter by an amount equal to twice the depth of rounding. Thus they have flat crests.

Drunken Thread. A thread in which the advance of the helix is irregular in every convolution or complete revolution of the thread. A drunken thread therefore has an erratic pitch.

Erratic Pitch. A pitch error that varies irregularly in magnitude over different lengths of thread.

Cumulative Pitch. This is the distance, measured parallel to the axis of the thread, between corresponding points on any two thread forms, whether in the same axial plane or not.

Progressive Error. If the pitch is uniform, but longer or shorter than its nominal value, it is said to have progressive error.

Periodic Error. If the errors vary in magnitude when measured

from thread to thread along the screw, and yet recur at regular intervals, they are called periodic errors.

Effect of Pitch Errors. It is axiomatic in screw thread measurement that an error in pitch virtually increases the effective diameter of a bolt and decreases the effective diameter of a nut. This is discussed more fully on page 168.

Helix Angle. In B.S. 84—1940 (Screw Threads of Whitworth Form) the term helix angle is used to describe the angle indicated as θ in

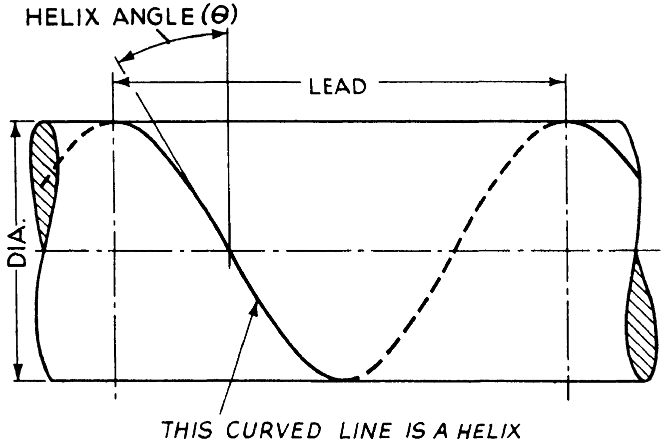


FIG. 117. SIMPLE HELIX DIAGRAM

Fig. 117, and defined as the angle made by the helix with a plane normal to the axis. The angle is measured in an axial plane.

In B.S. 436—1940, in definitions relating to helical gears, the angle indicated as θ in Fig. 117 is not defined in any way *but its complement is referred to as the helix angle.*

In B.S. 721—1937 (Worm Gearing) the B.S.I. describe the angle represented as θ in Fig. 117 as the *lead angle* (λ), the term generally used to describe it in worm gear work. In the same specification its complement is referred to as the *spiral angle* (σ).

It is well, therefore, in view of possible confusion to use the term helix angle for ordinary screw threads in the sense indicated in Fig. 117. Note that the helix has two dimensions, viz. lead and diameter. A helical curve winds round and along a cylinder and may be considered as the path of a point having regularly co-ordinated "forward-circular motion."

$$\text{Tangent of helix angle} = \frac{\text{lead of thread}}{\text{circumference}}$$

$$= \frac{\text{lead}}{\pi \times \text{diameter}}$$

$$\text{Cotangent of helix angle} = \frac{\pi \times \text{diameter}}{\text{lead}}$$

Tables of helix angles are given on pages 187–193.

On a screw thread we have the pitch diameter, the minor diameter, and the major diameter. The helix angle has its minimum value at the major diameter and maximum value at the minor diameter. The pitch diameter helix is usually considered when calculations are made.

An example of the change of helix angle as pitch diameter increases, pitch or lead remaining the same, is given in the following table:

HELIX ANGLES FOR SINGLE-START THREADS, 2 THREADS PER INCH
LEAD (OR PITCH) = $\frac{1}{2}$ IN.

Diameter . .	$1\frac{5}{8}''$	$2''$	$2\frac{3}{4}''$	$3\frac{1}{2}''$	$4''$
Helix Angle . .	6° 59′	5° 26′	3° 45′	2° 52′	2° 29′

Diameters

Major Diameter. In the case of a parallel thread this is the diameter of the imaginary cylinder, co-axial with the screw, which just touches the crests of an external thread or the roots of an internal thread. It is often referred to as the *outside diameter*, *crest diameter* or *full diameter*, on external threads.

Minor Diameter. In the case of a parallel thread this is the diameter of the imaginary cylinder, co-axial with the screw, which just touches the roots of an external thread or the crests of an internal thread. It is often referred to as the *root diameter* or *core diameter* on external threads.

Effective Diameter. In the case of a parallel thread this is the diameter of an imaginary cylinder, co-axial with the axis of the screw, which intersects the flanks of the threads in such a way as to make the widths of threads and widths of the spaces between the threads equal. If the *effective diameter cylinder* is imagined as generated by a straight line parallel to the axis of the screw we may call that line *the pitch line*. Measured along the pitch line the widths of the threads and the widths of the spaces are equal *on a perfect thread*. The effective diameter described above is also known as the *simple effective diameter* or *pitch diameter*.

On a perfect thread,

Effective dia. = major dia. − depth of thread

Or, as the B.S.I. state in B.S. 84,

Basic effective dia. = basic major dia. − standard depth of thread.
Basic minor dia. = basic major dia. − twice standard depth of thread.

NOTES

Probably the most important thread dimensions are effective diameter and angle. Between them they determine the quality of the fit between the screw and the nut. The crests and roots need not fit in the two members, for clearance is permitted, or even required between the screw and the nut, at those parts, which do not depend entirely upon other and more important dimensions.

The simple effective diameter of a screw is the value of its effective diameter as measured by using thread-measuring cylinders. This method takes no account of errors which may be present in the pitch or angles of the thread.

Compound, or Virtual, Effective Diameter. This is the effective diameter *over a specified length of thread,* and may be greater than the simple effective diameter by an amount due to errors in pitch and angle of thread.

NOTES

"The virtual effective diameter of a thread may be regarded as the effective diameter of the perfect thread with which it would just assemble over the prescribed length of engagement" (B.S. 84).

An error in pitch and/or in one or both of the flank angles virtually increases the effective diameter of a bolt and decreases the effective diameter of a nut.

Effect of Pitch Errors. It has been mentioned that an error in pitch virtually increases the effective diameter of a bolt and decreases the effective diameter of a nut.

If δp represents the maximum error in the axial displacement between any two points on a Whitworth form screw thread within the length of engagement, the corresponding virtual increase (decrease) in the effective diameter of the thread in the case of a bolt (nut) is given by,

$$\text{Virtual change in eff. dia.} = 1{\cdot}921 \times \delta p$$

For a B.A. thread ($47\frac{1}{2}°$) the expression becomes $2{\cdot}273\ \delta p$; for U.S. Nat. Thread, System International, and other 60° threads, the expression becomes $1{\cdot}732\ \delta p$.

The essential point to grasp is that *the virtual change in effective diameter,* calculated as shown above, gives the amount by which the effective diameter of a screw plug has to be below nominal size, or a screw ring above nominal size, to compensate for a certain error in pitch. If the screw plug is perfect, except for pitch error, it will not screw easily into a perfect ring gauge of the same nominal size *until its effective diameter has been reduced.*

Effect of Errors in Angle. If $\delta\theta_1$ and $\delta\theta_2$ represent the errors present in the flank angles (regardless of sign), the corresponding virtual increase (decrease) in the effective diameter of the thread in the case of a bolt (nut) is given by—

Whitworth Thread	$\delta E = 0{\cdot}0105 \times p(\delta\theta_1 + \delta\theta_2)$
B.A. Thread	$\delta E = 0{\cdot}0091 \times p(\delta\theta_1 + \delta\theta_2)$
60° Threads	$\delta E = 0{\cdot}0131 \times p(\delta\theta_1 + \delta\theta_2)$

Note that δE represents the virtual change in effective diameter, or difference in effective diameter; p = nominal pitch.

The essential point to grasp is that "the presence of errors in the angles of the flanks of a screw thread must be accompanied by a corresponding reduction in the effective diameter, if the screw is to *fit* a perfect ring gauge of the same nominal size" (*Notes on Screw Gauges*)*. In B.S. 93—1919 (B.A. Threads) the matter is excellently explained in the following terms—

"*Errors in pitch and angle can be met by a suitable alteration of effective diameter, and if the screw will accept a complete form "GO" gauge of*

* *Notes on Screw Gauges,* compiled at the National Physical Laboratory, is obtainable from His Majesty's Stationery Office, Kingsway, London, W.C.2.

suitable length, it is evident that the errors in pitch and angle do not prevent interchangeability, while provided that the screw rejects a "NOT GO" effective diameter gauge made to the prescribed limit of tolerance, it is clear that the screw does not differ so seriously from standard form as to be a loose fit."

The Effective Diameter Equivalent. On accurate work, as on screw gauges, it is essential to restrict the magnitude of these errors to small amounts and the simplest way of doing this is to fix a maximum value for *the equivalent of the combination of these two errors in terms of the effective diameter of the gauge.* This has been done in tables given in B.S. 919—1940 (Screw Thread Gauge Tolerances) which was issued as a war emergency specification and was based on the well-known National Physical Laboratory tables of screw-gauge tolerances. The latter tables are contained in *Notes on Screw Gauges*, published by His Majesty's Stationery Office, Kingsway, W.C.2.

The **effective diameter equivalent** can be calculated from the following formulae, given in B.S. 919—1940:

If δp = maximum error in the relative displacement of any two threads along the gauge,

$\delta\theta_1$ & $\delta\theta_2$ = errors in the slopes of the opposite flanks of the thread *regardless of sign*, in degrees,

δE = effective diameter equivalent of the above errors in the pitch and angles of the gauge.

For Whitworth Threads—

$$\delta E = (1{\cdot}9 \times \delta p) + 0{\cdot}010 \times p\,(\delta\theta_1 + \delta\theta_2)$$

For Metric and other 60° Threads—

$$\delta E = (1{\cdot}7 \times \delta p) + 0{\cdot}013 \times p\,(\delta\theta_1 + \delta\theta_2)$$

For B.A. Threads—

$$\delta E = (2{\cdot}3 \times \delta p) + 0{\cdot}009 \times p\,(\delta\theta_1 + \delta\theta_2)$$

Tables are given in B.S. 919—1940 (Screw Thread Gauge Tolerances) showing (1) Effective Diameter Equivalents of Error in Pitch, (2) Effective Diameter Equivalents of Errors in Angle, for Whitworth, B.A., and 60° Threads (S.I., U.S. National, etc.). Tables are also given, with worked examples, in *Notes on Screw Gauges* (H.M.S.O.).

Tables No. 19 and 20 in the Appendix of this book give the *Effective Diameter Equivalents of Errors in Angle* and *Errors in Pitch* for various thread systems.

WORMS

Worm. A worm is a special form of screw thread which works in conjunction with a wormwheel to connect "skew" shafts, i.e. shafts at any angle and not in the same plane. Usually the shafts are at right angles. The worm is usually the driving member and as it rotates its threads press against teeth cut in the rim of the wormwheel, causing it to rotate.

Two Main Classes of Worms. (1) The older design, having straight-sided rack-like threads *in an axial section*, usually having a *low pressure*

angle (usually 14½° or 15°), and having a *low lead angle* also. It is sometimes called the Brown and Sharpe, or B. & S., worm; also called the Involute worm.

(2) The newer high-efficiency worms such as those dealt with in B.S. 721—1937 (Worm Gearing). The British Standard worm has a normal pressure angle of 20° and it usually has a high lead angle.

Fig. 118 shows the usual proportions of worms in Class (1) in the above description, i.e. of B. & S. or Involute worms which are straight-sided in axial section.

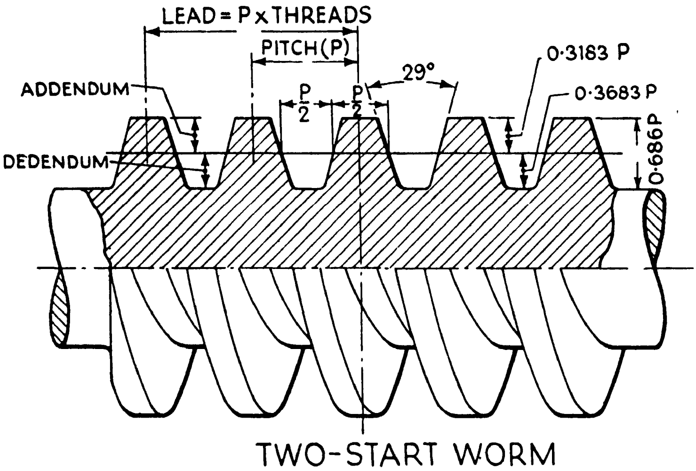


FIG. 118. INVOLUTE WORM PROPORTIONS
Proportions of Threads on an Axial Section.

Worms of the older design, having lead angles in the general neighbourhood of 10°, are often cut in a lathe, using the customary screw-cutting methods. Similarly their thread form is such as to enable them to be thread-milled or, in small sizes, thread-ground. Worms of this type are used primarily for obtaining a large velocity ratio. Worms of the newer design are generally multi-start and are designed mainly for high-efficiency power transmission. They have small diameters and large lead angles. In manufacture they are usually thread-milled and then finished by grinding. A typical "D.B.S." machine for the latter process is shown in Fig. 5.

BRIEF NOTES ON THE INVOLUTE HELICOID AND MODERN B.S. WORMS. The British standard form of worm thread is an involute helicoid, i.e. it is a screw or helicoidal surface so formed that on any *transverse section*, i.e. a section taken perpendicular to the axis of the screw, *the profile is the involute of a circle*, such circle being concentric with the axis of the entire screw surface and being known as the *base circle*. To use the terminology of B.S. No. 721—1937—

"*The standard form of worm thread is involute in section at right angles to the axis and is such as would be generated by a basic rack surface having a straight-sided normal section.*"

An involute helicoidal surface can be imagined as generated by a straight line which moves in a helical path, always being tangential to a helix having the same lead as that of the helicoidal surface being produced. See the *generating line* in Fig. 119. An involute helicoidal surface is convex everywhere, except along the straight generating line.

Readers with an elementary knowledge of the geometry of toothed gearing will realize that the British standard worm is, in essence, a

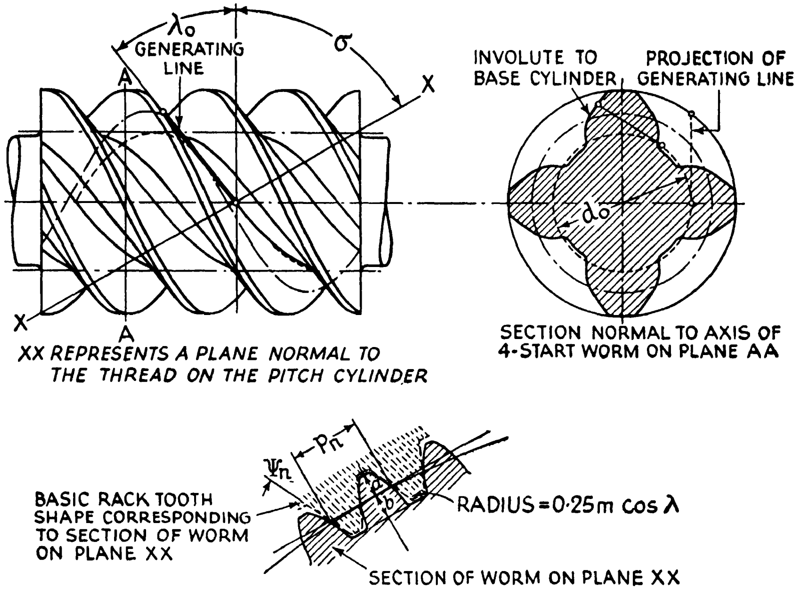


FIG. 119. BASIC DIMENSIONS OF B.S. WORM THREAD AND GENERATING RACK

single helical involute pinion. Worms made to this design, as opposed to the older B. & S. 29° type, are comparatively easy to manufacture and to check, inasmuch as the thread profile contains a straight line. This is not a matter that can be discussed satisfactorily in brief compass, but readers interested in worms and other types of gears are referred to *Gears, Gear Production and Measurement*, by the same authors.

See Fig. 119, reproduced from B.S. 721 by permission. In that diagram many of the symbols used in the following definitions are given. All symbols given below are these recommended by the B.S.I.

STANDARD SYMBOLS AND USEFUL DEFINITIONS

d_o = the **base diameter,** i.e. the diameter of the base cylinder of the worm, from which cylinder the involute thread form is developed.

λ = the **lead angle,** or the angle between a tangent to the thread helix on the pitch cylinder and a plane perpendicular to the axis of the worm.

λ_o = the **base lead angle,** or the angle between a straight line lying in the surface of the thread tangential to the base cylinder, and a plane at

right angles to the axis. This is equal to the lead angle on the base cylinder.

ψ_a = the **axial pressure angle** of the worm, i.e. the acute angle between the axis of the worm and a normal to the profile on an axial section at a point on the pitch cylinder.

ψ_n = the **normal pressure angle** of the worm, i.e. the acute angle between a normal to the thread surface at any point on the pitch cylinder and the tangent plane to the pitch cylinder at that point. This is equal to the normal pressure angle of the generating rack and in British practice is usually 20°.

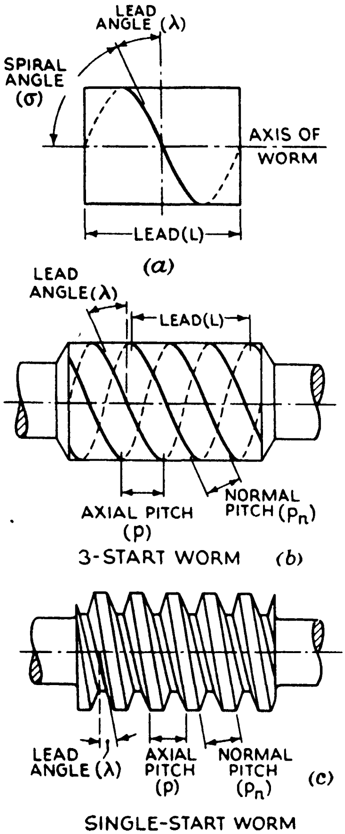


FIG. 120. WORM ANGLES AND PITCHES

σ = the **spiral angle,** or the complement of the lead angle, i.e. lead angle + spiral angle = 90°.

a = the **addendum** of the worm thread, i.e. height of thread above pitch cylinder.

b = the **dedendum** of the worm thread, i.e. depth of thread below pitch cylinder.

p = the **axial pitch** (or linear pitch) of the worm, i.e. the distance measured parallel to the axis between similar faces of successive threads. On B.S. worms the axial *thickness* of the threads at one-half the total depth is equal to one-half of the axial pitch.

m = the **module,** i.e. the axial pitch divided by π. Alternatively, module = 0·3183 × axial pitch.

p_n = the **normal pitch** of the worm, or the length of arc between similar faces of successive threads measured along a helix lying in the pitch cylinder normal to the thread helix. It is equal to the normal pitch of the generating rack.

L = the **lead** of the worm, i.e. the distance measured parallel to the axis by which each thread advances per revolution. Lead = axial pitch × number of starts. On a 3-start worm of 1 in. axial pitch the lead is 3 in.

$p/2$ or g_a = the **axial thickness of the worm thread.** It is the distance between opposite faces of the same thread measured on the pitch cylinder in a direction parallel to the axis. On B.S. worms the axial thickness of the threads *at one-half the total depth* is equal to one-half of the axial pitch. On straight-sided involute worms the axial thickness of the threads *at the pitch line* is equal to one-half of the axial pitch.

g_n = the **normal thickness of the worm thread.** It is length of arc between opposite faces of the same thread along a helix which lies in the pitch cylinder and is normal to the thread helix.

g_{nc} = the **normal chordal thickness** of the thread. It is the length of the chord of the arc of the normal helix described in the previous definition.

The symbol for pitch of *threads* employed generally in this book is P. In several B.S. specifications it is given as p. In reproducing standard definitions,

therefore, we use p, otherwise we prefer P which has wide general currency. Differentiation between P and p is more important in gearing than in general screw-thread work.

OTHER USEFUL DEFINITIONS

The **accumulated pitch error** is the algebraic sum of all the pitch errors in any number of threads under consideration.

The **shape error** is the maximum displacement of any point on the thread from the theoretical form. The direction of measurement of this error is at right angles to the theoretical tooth surface.

HAND. " Right- " or " Left- " hand Helix. Suppose that when a point moves along a helix, in a clockwise direction looking along the axis, it moves away from the observer, the helix is "Right" hand. If it moves towards the observer the helix is "Left" hand.

Right-hand worms are those in which the general direction of the thread(s) follow(s) a right-hand helix.

Left-hand worms are those in which the general direction of the thread(s) follow(s) a left-hand helix.

USEFUL FORMULAE—WORMS

British Standard Involute Helicoidal Type

Lead (L) = axial pitch (p) $\times$ No. of threads or starts
= pitch diameter (d) $\times$ π $\times$ cotangent of spiral angle (σ).

Axial pitch (p) = lead $\div$ No. of starts
= $\pi \times$ module (m)
= p_n cosec σ.

Normal pitch (p_n) = $p \cos \lambda$.

Module (m) = axial pitch (p) $\div \pi = 0{\cdot}3183\,p$.

Normal module = $m \cos \lambda$.

(Note that the term *module* used in the foregoing and similar equations signifies the *axial module,* just as the term *pitch* used without qualification and, applied to worms, signifies *axial pitch.*)

Normal diametral pitch = diametral pitch (P) $\div \cos \lambda$.

Addendum (a) = m.
= dedendum of worm wheel − clearance.

Dedendum (b) = $m\,(2{\cdot}2 \cos \lambda - 1)$.
= addendum of worm wheel + clearance.

Clearance (c) = $0{\cdot}2\,m \cos \lambda$ = dedendum − addendum.

Overall diameter (j) = pitch diameter (d) + (2 $\times$ addendum).

Root diameter (i) = pitch diameter (d) − (2 $\times$ dedendum).

Base diameter (d_0) = $L/\pi \tan \lambda_0$.

Pitch diameter = overall diameter − (2 $\times$ addendum).

(The term *pitch diameter,* applied to worms, has disadvantages. However the pitch diameter of a worm is fixed for purposes of calculation by expressing it as a certain multiple (denoted by q) of the module. Thus, if the axial module is 0·15 the axial pitch is $0{\cdot}15 \times \pi$. If q is taken as 6 the *nominal pitch diameter* is $6 \times 0{\cdot}15 = 0{\cdot}9$ in. From this we have, q = diameter $\div$ module.)

Axial Thickeness of Worm Thread (g_a) = $0{\cdot}5\pi m$. (On B.S. worms

this is measured at half the total depth of the thread. Total depth = addendum + dedendum.)

Lead Angle (λ). See notes on "Helix Angle" on page 166.

$$\text{Tan } \lambda = \text{lead}/(\pi \times \text{diameter}).$$

(In this equation *diameter* means *nominal pitch diameter.*)

Involute or B. & S. Worms—29° Thread Angle

Addendum = 0·3183 p; dedendum = 0·3683 p; clearance = 0·05 p; whole depth = 0·6866 p.

Width of flat at bottom of thread space = 0·3100 p.

Width of flat at top of thread = 0·3354 p.

Thickness of thread on pitch line = 0·5 p.

HOBS FOR INVOLUTE WORMS—29° THREAD ANGLE

Addendum = 0·3683 p; dedendum = 0·3183 p; whole depth = 0·6866 p. The outside diameter of the hob exceeds that of the worm by twice the clearance + 0·005″ ($2c$ + 0·005″).

For a fuller description of Worm Gearing, readers are referred to *Gears, Gear Production, and Measurement*, by A. C. Parkinson and W. H. Dawney (Pitman).

CHAPTER XVII

LIMITS AND TOLERANCES, WITH SPECIAL REFERENCE TO SCREW THREADS

THE demand for precision in the production of screwed components extends steadily. On the one hand we see a reduction in the permitted variations in size, on the other an increase in the number of classes of work made to fine limits. Thread-grinding is essentially a precision operation which has enabled an increase in output without sacrifice of quality, in fact with improvement of quality. Nowadays the term "precision production" means the manufacture of components within specified or tabulated limits of size which themselves depend upon prescribed tolerances. In order to give clear unambiguous point and meaning to references and terms used in various parts of this book in regard to limit systems we provide the ensuing notes and definitions. We commence by defining terms generally employed in *any system of limits and fits*, pass on to their application to limit-system dimensioning of screw-thread parts with special reference to effective diameter tolerances, and finally give extracts from B.S. Screw-thread Tables so as to direct attention to the relative amounts of tolerance for different classes of fit as well as to the direction of the tolerance in relation to the basic dimension.

(a) LIMITS

Nominal Size. This is the dimension or size of a part referred to as a matter of convenience.

Basic Size. This is the size in reference to which all limits of variation are assigned.

NOTES

The nominal and basic sizes are in many cases equal.

Thus see B.S. 84—1940 (Screw Threads of Whitworth Form). Table No. 1 is headed *Basic Sizes*. Column 1 gives nominal diameters from $\frac{1}{8}$ in. to 6 in. For a screw of $\frac{1}{2}$ in. nominal diameter the major diameter is given as 0·5000 in. For a screw of 1 in. nominal diameter the major diameter is given as 1·0000 in. These are all basic sizes.

Tolerance. This is the margin of error allowed on dimensions so as to allow for reasonable inaccuracy in workmanship and appliances. In B.S. 164 (Limits and Fits), tolerance is defined as "*the difference between the high and low limits of size for that dimension, or the variation tolerated in the size of that dimension to cover reasonable imperfections in workmanship.*"

Limits of Size, or Limits. These are the two extreme permissible sizes for a dimension. The high limit for a dimension is the largest size permitted for that particular dimension; the low limit for a dimension is the smallest size permitted for that dimension.

EXAMPLES

Hole 2 in. nominal diameter.

High (H) limit	2·0012 in.
Low (L) limit	1·0098 in.
Tolerance	0·0014 in.

In this case 2·0012 in. and 1·0098 in. are the limits of size.

Another way of writing these *limit dimensions*, or *limits*, is to commence by writing the *basic size* and then writing the *limits of tolerance*. Thus,

$2 \text{ in.} \begin{matrix} +\,0{\cdot}0012 \\ -\,0{\cdot}0002 \end{matrix}\Big\}$ Here + 0·0012 and − 0·0002 are the limits of tolerance, but the tolerance is 0·0014.

Limits of Tolerance. These are the differences between the two limits of size (or limits) and the basic size, as shown in the foregoing example. The algebraic difference between the *limits of tolerance* of a dimension is equal to the *tolerance* on that dimension.

(b) LIMITS AND FITS

Fit. The fit between two mating parts is defined as the relationship existing between their dimensions, which governs the amount of play or, alternatively, of interference that arises when they are assembled together.

Allowance. This is a deliberately prescribed difference in dimensions in order to obtain a certain class of fit. It may be a positive or negative amount according to the type or class of fit required.

In Amendment No. 1 (June, 1942) to B.S. 84—1940, allowance in relation to screw threads is defined as follows: *The allowance is a prescribed difference between the high limit for an external part and the low limit for an internal part in order to provide a certain class of fit.*

NOTES

Tolerance and allowance are two entirely separate and distinct things.

Minimum Allowance is the difference between the largest shaft and the smallest hole.

Maximum Allowance is the difference between the smallest shaft and the largest hole.

A positive (or plus) allowance results in a clearance fit whilst a negative (or minus) allowance results in an interference fit.

Fig. 121 shows the method adopted by the B.S.I. for illustrating diagrammatically the limits and tolerances for a hole and its mating shaft. It is reproduced by permission. The hole and shaft are drawn in contact at the bottom so that the whole of their tolerances are shown at the top. Only the upper parts of such "limits diagrams" are used customarily and usually they are simplified to include only the tolerance "bands" or "zones." The latter are shown separately at the right of the diagram.

In the **Newall System of Limits** there are two grades of *tolerances for standard holes*, known as Classes A and B respectively, the selection of which is for the user's discretion. The choice depends on the quality of the work required.

There are various *Classes of Allowances for Shafts* in the Newall system, as follows,

FORCE FITS, Class F. Shafts made to the figures in the Newall tables of Force Fits require hydraulic pressure to force them into the holes. Alternatively the holes have to be expanded by heating prior to assembly of shaft with hole.

DRIVING FITS, Class D. Produce shafts that have to be driven into the holes.

PUSH FITS, Class P. Produce shafts that can be pushed into the holes, but the shafts are not sufficiently free to rotate without seizure.

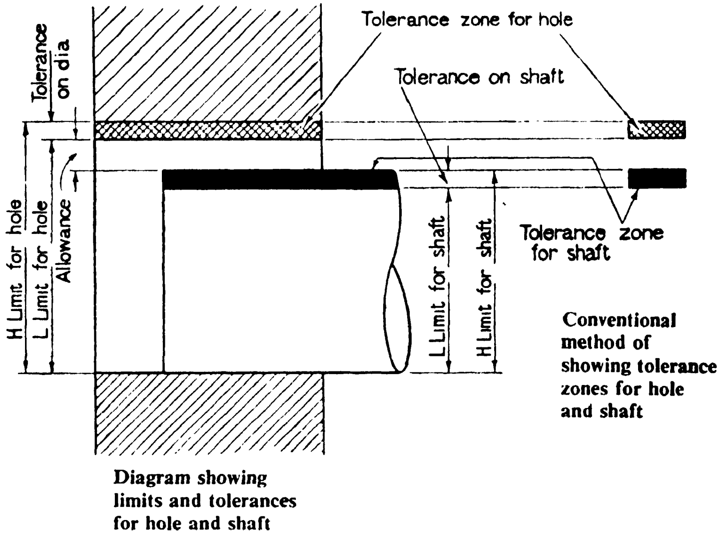


FIG. 121. B.S. CONVENTIONAL METHOD OF SHOWING TOLERANCE ZONES FOR HOLE AND SHAFT
(See B.S. 164—1924 (War-time Edition, 1941).)

RUNNING FITS, Classes X, Y, and Z. These are the most frequently used fits.

Class X, for work where easy fits are required.

Class Y, for high speeds and good average machine work.

Class Z, for fine tool work.

The B.S. System of Limits is set out in B.S. 164—1924 (War-time Issue, 1941). The tables, like the Newall tables, are compiled on a *hole basis*, that is the hole is the constant member and different fits are obtained by varying the size of the shaft. Provision is made for the use of either the *unilateral system* or the *bilateral system*, but the B.S.I. recommend that unilateral limits be used where possible.

The Unilateral System. The lower limit of the hole is equal to the basic size of the hole, i.e. when the tables are compiled on a hole basis. In this system the tolerance is in one direction only from the nominal

size, and is usually positive; in other words a hole in the unilateral system is the nominal size or larger.

The Bilateral System. The limits for the basic member are disposed one above and the other below the basic size for that member. Thus, the tolerance extends in both directions (but not always in equal amounts) from the nominal size. Therefore holes in the bilateral system may be smaller or larger than the nominal size. The B.S.I. formerly approved the shaft basis as the constant member for a limit system but that was reversed when B.S. 164—1924 was published, for in that specification (and subsequent publications) the B.S.I. recommend the adoption of the hole as the constant member.

UNILATERAL		BILATERAL	
H. 2·0016 L. 2·0000	or 2 in. $\begin{matrix} + 0{\cdot}0016 \\ - 0 \end{matrix}$	H. 2·0008 L. 1·9992	or 2 in. $\begin{matrix} + 0{\cdot}0008 \\ - 0{\cdot}0008 \end{matrix}$

A table in B.S. 164 gives limits of tolerance, both unilateral and bilateral, for holes. Another table gives a series of fourteen different shafts which may be used with either unilateral or bilateral holes. This series makes provision for any "fit," from a "heavy drive" to a "coarse clearance." For any given hole, then, provision is made in B.S. 164 for fourteen different fits. In these tables specification by letters is used for various classes of holes, e.g. *B*, *U*, *V*, *W*, etc. Similarly the shafts are specified by letters, e.g. *F*, *E*, *D*, *C*. The designation of a fit is therefore made by using two letters, e.g. *UF*, *UK*, etc. Three *Classes of Fit* are specified viz. *Interference*, *Transition*, *Clearance*.

These notes comprise a brief summary of the main features of the two Systems of Limits used in British practice. For a fuller description readers are referred to *Engineering Inspection*, by A. C. Parkinson (Pitman).

B.S. LIMITS AND TOLERANCES FOR SCREW THREADS. B.S. 84—1940* applies to parallel screw threads of Whitworth Form with principal reference to

The British Standard Whitworth (B.S. Whit.) Series.
The British Standard Fine (B.S. Fine) Series.
The British Standard Pipe (B.S. Pipe) Parallel Thread Series.

It gives the recognized basic series of diameters coupled with their corresponding pitches, and also recommended tolerances and limits for these series of threads.

In addition it gives recommended tolerances for other "special" screw threads of Whitworth form up to 20 in. diameter, associated with the various pitches and lengths of engagement commonly met with in practice.

Three Grades of Fit

Three grades of accuracy or fit are provided for.

*** All B.S.I. Specifications are obtainable from the British Standards Institution, 28 Victoria Street, London, S.W.1.**

CLOSE FIT. Gives a fine snug fit. For special work requiring refined accuracy.

MEDIUM FIT. Applicable to the better class of ordinary interchangeable screw threads.

FREE FIT. Applicable to the great bulk of threads of ordinary commercial quality.

NOTES

The two threads of any mating pair are ordinarily made to the same grade. In special circumstances they can be specified to different grades.

B.S. 84 does *not* apply to screw threads associated with interference fits, such as those on the "metal ends" or "steam ends" of studs and in the corresponding tapped holes.

When the reader examines the tolerances in the following examples he will realize the force of the workshop phrases: *screws are made nominal to minus: nuts are made nominal to plus.*

Nominal to minus. The tolerance is minus, and applies from the nominal diameter to below nominal diameter.

Nominal to plus. The tolerance is plus, and applies from the nominal diameter to above nominal diameter.

SCREW THREAD EXAMPLES WITH COMMENTARY

(1) **Examination of Effective Diameter Dimensions ½ in. dia. B.S.F.** See B.S. 84—1940. All dimensions in inch units.

Basic effective diameter = 0·4600 (from Basic Sizes table).

From Tables of Close Fit

BOLT.	Effective dia. (max.)	= 0·4600	NUT.	Effective dia. (max.)	= 0·4633
	Effective dia. (min.)	= 0·4567		Effective dia. (min.)	= 0·4600
	Tolerance	= 0·0033		Tolerance	= 0·0033

The limit dimensions could be written thus:

$0{\cdot}4600 \begin{smallmatrix} +\ 0 \\ -\ 0{\cdot}0033 \end{smallmatrix}$ $\qquad$ $0{\cdot}4600 \begin{smallmatrix} +\ 0{\cdot}0033 \\ -\ 0 \end{smallmatrix}$

From Tables of Medium Fit

BOLT.	Effective dia. (max.)	= 0·4600	NUT.	Effective dia. (max.)	= 0·4650
	Effective dia. (min.)	= 0·4550		Effective dia. (min.)	= 0·4600
	Tolerance	= 0·0050		Tolerance	= 0·0050

From Tables of Free Fit

BOLT.	Effective dia. (max.)	= 0·4600	NUT.	Effective dia. (max.)	= 0·4674
	Effective dia. (min.)	= 0·4526		Effective dia. (min.)	= 0·4600
	Tolerance	= 0·0074		Tolerance	= 0·0074

Study the limits given for *Medium Fit* and the following comparisons between the minimum and maximum allowances:

Min. eff. dia. of nut	= 0·4600	
Max. eff. dia. of bolt	= 0·4600	
Min. allowance	= 0·0000	(negative allowance)
Max. eff. dia. of nut	= 0·4650	
Min. eff. dia. of bolt	= 0·4550	
Max. allowance	= 0·0100	(positive allowance)

What These Figures Reveal. The basic size represents the upper limit for the external thread and also the lower limit for the internal thread for all three grades of fit. This applies to all except bolts and nuts of stainless steel in regard to which special recommendations are made in view of the tendency of bolts and nuts of this material to seize if closely fitted.

Basic Formula for Effective Diameter Tolerances. The formula used in compiling the tables was as follows—

Tolerance on Effective Diameter*

$$= 0{\cdot}002 \sqrt[3]{D} + 0{\cdot}003 \sqrt{L} + 0{\cdot}005 \sqrt{p}$$

where D = major dia. of thread in inches
L = length of engagement in inches
p = pitch in inches.

[taking length of engagement as being equal to the nominal diameter of the thread for the B.S. Whit. and B.S. Fine threads. In the case of B.S. Pipe threads the average length of engagement upon which the calculations were based is given in the B.S. Pipe tables of limits and tolerances in B.S. 84.]

Thus the tabulated effective diameter tolerances for B.S. Whit., B.S. Fine and B.S. Pipe (parallel) threads take into account the effects of pitch and angle error.

Effective Diameter Tolerances for Special Whitworth Threads. In B.S. 84 an entirely separate set of three tables is given for other "special" threads of Whitworth form, outside the three standard series. From these tables it is possible to ascertain appropriate effective diameter tolerances by considering the three elements pitch, diameter, and length of engagement. If these tables are strictly followed the result is that for threads of the same pitch and diameter, but with different lengths of engagement, there are different effective diameter tolerances. This requires the use of different *NOT GO* gauges (other than those for the minor diameter of the nut) for threads with the same pitch and diameter but differing in length. To overcome the need for so many gauges during the war the B.S.I. issued a *War Emergency Revision* known as *Amendment No.* 1; *June* 1942, to B.S. 84—1940. This contains simplified tables superseding those originally given in B.S. 84—1940 for "special" threads. These simplified tables apply only to the "special" threads and *not* to the thread tables for the B.S. (Whit.), B.S. Fine, and B.S. (Pipe) series. Their merit is that they provide one effective diameter tolerance for each combination of pitch and diameter.

(2) Examination of Major Diameter Dimensions

½ in. dia. B.S.F. See B.S. 84—1940. All dimensions in inch units. Basic major dia. = 0·5000.

* This applies to medium fits. Values obtained by means of this formula must be increased by 50 per cent for free fits and decreased by 33⅓ per cent for close fits.

From Tables of Close Fit

BOLT.	Major dia. (max.) = 0·5000		NUT.	Major dia. (max.) = not given	
	Major dia. (min.) = 0·4937			Major dia. (min.) = 0·5000	
	Tolerance = 0·0063			Tolerance = not given.	

From Tables of Medium Fit

BOLT.	Major dia. (max.) = 0·5000	NUT.	Major dia. (max.) = not given
	Major dia. (min.) = 0·4919		Major dia. (min.) = 0·5000
	Tolerance = 0·0081		Tolerance = not given

From Tables of Free Fit

BOLT.	Major dia. (max.) = 0·5000	NUT.	Major dia. (max.) = not given
	Major dia. (min.) = 0·4894		Major dia. (min.) = 0·5000
	Tolerance = 0·0106		Tolerance = not given

What These Figures Reveal. The basic size represents the upper limit for the bolt and also the lower limit for the nut.

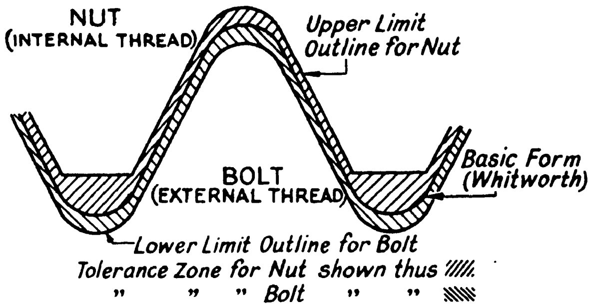


FIG. 122. LIMITING OUTLINES FOR BOLTS AND NUTS

No tolerance is given for the major diameter of internal threads (nuts). The B.S.I. recommend, however, that the radius at the major diameter of internal threads should never be less than one-half the standard radius for the pitch of the thread concerned. The standard radius for Whitworth threads is $0{\cdot}137329 \times$ pitch.

Tolerance on major diameter exceeds that on the effective diameter by an amount equal to $0{\cdot}01 \sqrt{p}$.

(3) Examination of Minor Diameter Dimensions

$\frac{5}{8}$ in. dia. B.S.W. See B.S. 84/1940.

Basic minor dia. = 0·5086 (from Basic Sizes table)

From Tables of Close Fit

BOLT.	Minor dia. (max.) = 0·5086	NUT.	Minor dia. (max.) = 0·5338
	Minor dia. (min.) = 0·5010		Minor dia. (min.) = 0·5086
	Tolerance = 0·0076		Tolerance = 0·0252

From Tables of Medium Fit

BOLT.	Minor dia. (max.) = 0·5086	NUT.	Minor dia. (max.) = 0·5338
	Minor dia. (min.) = 0·4970		Minor dia. (min.) = 0·5086
	Tolerance = 0·0116		Tolerance = 0·0252

From Tables of Free Fit

BOLT.	Minor dia. (max.) = 0·5086	NUT.	Minor dia. (max.) = 0·5338
	Minor dia. (min.) = 0·4942		Minor dia. (min.) = 0·5086
	Tolerance = 0·0144		Tolerance = 0·0252

Tolerance on minor diameter exceeds that on the effective diameter by an amount equal to $0{\cdot}013\sqrt{p}$ for close fits, and $0{\cdot}02\sqrt{p}$ for medium and free fits.

What These Figures Reveal. The basic size represents the upper limit for the bolt and also the lower limit for the nut.

The minor diameter tolerances are so devised as to permit of a tapping drill being used of ample size to prevent binding at the root of the tap. Generous tolerances are allowed on the minor diameters of internal threads. If full advantage is taken of these the crests of the threads will, of course, be flat. See Fig. 122.

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TABLE NO. 1. **WHEEL R.P.M. AND S.F.P.M.**

Wheel Dia. in.	Wheel Peripheral Speed (S.F.P.M.) 3500	4000	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10,000
10	1340	1530	1910	2100	2290	2480	2670	2860	3060	3250	3440	3630	3820
11	1220	1400	1720	1910	2080	2250	2430	2600	2770	2950	3130	3290	3470
11½	1160	1330	1650	1810	1970	2130	2290	2450	2610	2860	3030	3180	3340
12	1110	1270	1590	1750	1910	2070	2230	2390	2550	2700	2870	3020	3180
12½	1070	1220	1530	1680	1830	1990	2140	2300	2450	2590	2750	2900	3010
13	1030	1170	1470	1620	1760	1910	2060	2200	2350	2490	2640	2790	2930
13½	1000	1130	1410	1560	1700	1840	1990	2120	2260	2400	2550	2690	2830
14		1090	1360	1500	1640	1770	1910	2050	2180	2320	2460	2590	2730
14½		1060	1310	1450	1580	1710	1840	1990	2110	2240	2370	2500	2640
15		1020	1270	1400	1520	1650	1780	1910	2040	2160	2290	2420	2550
15½		1000	1230	1350	1470	1600	1720	1850	1990	2100	2220	2350	2390
16			1190	1310	1430	1550	1670	1790	1910	2030	2150	2270	2320
16½			1160	1280	1390	1500	1630	1750	1850	1980	2090	2200	2250
17			1120	1240	1350	1460	1580	1680	1790	1910	2020	2130	2190
17½			1090	1200	1310	1420	1530	1640	1750	1850	1970	2070	2120
18			1060	1170	1270	1380	1490	1590	1700	1790	1910	2020	2060
18½			1030	1140	1230	1340	1450	1550	1650	1750	1880	1970	2020
19			1000	1110	1200	1300	1410	1510	1610	1700	1830	1910	1980
19½				1080	1180	1270	1370	1470	1570	1650	1780	1860	1940
20				1050	1140	1240	1340	1430	1530	1610	1720	1810	1910

Wheel R.P.M.

TABLE NO. 2. **WHEEL R.P.M. AND S.F.P.M. FOR INTERNAL GRINDING**

Wheel Dia. in.	Wheel Peripheral Speed (S.F.P.M.) 3000	4000	5000	5500	6000	6500	7000	7500	8000	8500	9000	10,000	12,000	14,000
½	22,920	30,590	38,200	42,000	45,840	49,660	53,480	57,300	61,120	64,940				
1	11,460	15,280	19,100	21,000	22,920	24,830	26,740	28,650	30,590	32,470	34,380	38,200	45,840	
1½	7,640	10,190	12,740	14,000	15,280	16,560	17,830	19,100	20,370	21,640	22,920	25,480	30,560	35,660
2	5,730	7,640	9,550	10,500	11,460	12,420	13,370	14,330	15,280	16,240	17,190	19,100	22,920	26,740
2½	5,000	6,120	7,640	8,400	9,180	9,940	10,700	11,460	12,230	13,000	13,760	15,280	18,340	21,400
3		5,090	6,370	7,000	7,640	8,280	8,910	9,500	10,190	10,820	11,460	12,740	15,280	17,830
3½	Wheel R.P.M.			5,250	5,730	6,200	6,690	7,160	7,640	8,120	8,600	9,550	11,460	13,370
4						5,000	5,350	5,730	6,120	6,500	6,880	7,640	9,170	10,700

TABLE NO. 3. **WORK SPEED—S.F.P.M.**

Work Dia. in.	Revolutions per Minute of Work Spindle: 0·5	0·75	1	1·5	2	3	4	5	6	8	10	15	20	30	40	50	60	100
1/8								0·20	0·20	0·32	0·33	0·51	0·65	1·01	1·31	1·64	2·00	3·27
3/16							0·20	0·25	0·28	0·40	0·49	0·75	0·98	1·43	1·94	2·46	2·88	4·91
1/4		Work Speed S.F.P.M.				0·20	0·26	0·33	0·38	0·52	0·65	0·99	1·31	1·84	2·64	3·27	3·68	6·54
5/16						0·24	0·32	0·41	0·48	0·65	0·82	1·20	1·63	2·36	3·27	4·10	4·72	8·20
3/8					0·20	0·28	0·38	0·49	0·56	0·76	0·98	1·40	1·94	2·86	3·98	4·95	5·72	9·81
7/16					0·24	0·36	0·48	0·58	0·72	0·98	1·15	1·84	2·30	3·68	4·61	5·07	7·36	11·5
1/2				0·20	0·27	0·39	0·52	0·66	0·78	1·04	1·31	1·94	2·62	3·91	5·24	6·55	7·82	13·1
5/8				0·24	0·33	0·48	0·64	0·82	0·97	1·28	1·63	2·36	3·26	4·71	6·56	8·15	9·42	16·3
3/4			0·20	0·27	0·39	0·57	0·78	0·97	1·15	1·56	1·94	2·68	3·88	5·71	7·76	9·71	11·42	19·4
7/8			0·23	0·36	0·46	0·69	0·92	1·15	1·32	1·84	2·29	3·58	4·58	6·91	9·17	11·5	13·82	22·9
1		0·20	0·26	0·40	0·53	0·78	1·07	1·32	1·56	2·14	2·64	3·93	5·28	7·86	10·5	13·2	15·7	26·4
1 1/8		0·23	0·30	0·44	0·59	0·91	1·18	1·49	1·81	2·36	2·97	4·62	5·94	9·24	11·9	14·9	18·5	29·7
1 1/4		0·24	0·33	0·48	0·65	0·99	1·30	1·64	1·97	2·61	3·27	4·95	6·54	9·92	13·1	16·3	19·8	32·7
1 3/8		0·27	0·36	0·54	0·72	1·08	1·44	1·80	2·13	2·88	3·60	5·28	7·20	10·8	14·4	18·0	21·6	36·0
1 1/2	0·20	0·29	0·39	0·58	0·79	1·17	1·58	1·97	2·31	3·16	3·93	5·89	7·86	11·7	15·7	19·7	23·1	39·3
1 5/8	0·22	0·33	0·43	0·66	0·85	1·29	1·70	2·13	2·58	3·41	4·25	6·55	8·50	12·9	16·9	21·3	25·1	
1 3/4	0·23	0·35	0·46	0·70	0·92	1·38	1·85	2·31	2·76	3·68	4·62	7·15	9·24	13·8	18·5	23·1	27·6	
1 7/8	0·25	0·37	0·50	0·74	0·99	1·50	1·98	2·48	3·10	3·96	4·95	7·40	9·92	15·1	19·8	25·0	30·1	
2	0·26	0·39	0·53	0·78	1·05	1·59	2·10	2·64	3·18	4·21	5·28	7·76	10·5	15·9	21·0	26·5	31·8	
2 1/4	0·29	0·44	0·59	0·88	1·18	1·77	2·36	2·95	3·54	4·72	5·89	8·88	11·9	17·7	23·8	29·5	35·4	
2 1/2	0·33	0·49	0·66	0·98	1·31	1·96	2·62	3·28	3·92	5·24	6·55	9·75	13·1	19·6	26·3	32·7	39·3	
2 3/4	0·36	0·54	0·72	1·08	1·43	2·16	2·86	3·58	4·32	5·72	7·15	10·5	14·4	21·6	28·8	36·0		
3	0·40	0·60	0·79	1·20	1·58	2·40	3·16	3·96	4·80	6·32	7·92	12·4	15·7	23·8	31·5	39·3		
3 1/4	0·42	0·63	0·85	1·26	1·69	2·52	3·39	4·23	5·04	6·78	8·45	12·6	16·9	25·4	33·8			
3 1/2	0·46	0·69	0·92	1·39	1·85	2·78	3·70	4·59	5·55	7·40	9·17	13·9	18·4	27·6	36·8			
3 3/4	0·49	0·75	0·98	1·50	1·95	3·01	3·90	4·88	6·02	7·80	9·75	15·1	19·5	30·1	39·3			
4	0·53	0·80	1·05	1·60	2·10	3·20	4·21	5·25	6·40	8·42	10·5	16·0	21·0	31·6				
4 1/4	0·55	0·85	1·11	1·70	2·22	3·40	4·44	5·55	6·80	8·88	11·1	16·9	22·2	33·8				
4 1/2	0·59	0·90	1·18	1·80	2·36	3·60	4·72	5·90	7·15	9·44	11·8	18·4	23·6	36·8		Work Speed S.F.P.M.		
4 3/4	0·62	0·94	1·24	1·86	2·48	3·72	4·96	6·20	7·40	9·92	12·4	18·6	24·8	37·2				
5	0·66	0·99	1·31	1·99	2·64	3·93	5·28	6·60	7·96	10·5	13·2	19·8	26·4	39·3				
5 1/2	0·72	1·08	1·43	2·16	2·86	4·29	5·72	7·15	8·49	11·4	14·3	21·6	28·6					
6	0·79	1·19	1·58	2·38	3·16	4·74	6·32	7·90	9·48	12·6	15·8	23·8	31·6					
6 1/2	0·85	1·27	1·69	2·54	3·38	5·07	6·76	8·49	10·1	13·5	16·9	25·4	36·8					
7	0·92	1·38	1·85	2·76	3·68	5·55	7·37	9·20	11·1	14·7	18·4	27·6	36·8					

TABLE NO. 4. **HELIX ANGLES BASED ON PITCH DIAMETERS AND T.P.I.**

PITCH DIAMETER (IN INCHES)

T.P.I.	0·10	0·12	0·14	0·16	0·18	0·20	0·22	0·24	0·26	0·28	0·30	0·32	0·34	0·36	0·38	0·40
4				28° 48′	25° 20′	22° 26′	20° 46′	18° 48′	17° 28′	16° 16′	15° 12′	14° 16′	13° 20′	12° 41′	12° 0′	11° 20′
5			26° 0′	23° 20′	20° 40′	18° 6′	16° 39′	15° 20′	14° 6′	13° 0′	11° 28′	10° 53′	10° 38′	10° 9′	9° 36′	9° 0′
6	28° 26′	25° 12′	21° 40′	19° 12′	17° 0′	15° 28′	13° 44′	12° 32′	11° 40′	10° 54′	10° 8′	9° 40′	9° 1′	8° 26′	8° 0′	7° 38′
7	26° 0′	21° 36′	18° 36′	16° 24′	14° 28′	13° 4′	11° 48′	10° 44′	10° 0′	9° 14′	8° 53′	8° 12′	7° 41′	7° 14′	6° 51′	6° 32′
8	22° 22′	18° 54′	16° 15′	14° 24′	12° 40′	11° 6′	10° 23′	9° 29′	8° 44′	8° 8′	7° 35′	7° 8′	6° 40′	6° 19′	6° 1′	5° 44′
9	19° 36′	16° 52′	14° 36′	12° 48′	11° 22′	10° 4′	9° 24′	8° 24′	7° 54′	7° 16′	6° 44′	6° 24′	6° 0′	5° 38′	5° 21′	5° 5′
10	17° 57′	15° 22′	13° 0′	11° 40′	10° 20′	9° 4′	8° 19′	7° 40′	7° 3′	6° 30′	6° 4′	5° 44′	5° 28′	5° 4′	4° 48′	4° 32′
11	16° 16′	13° 52′	11° 22′	10° 28′	9° 16′	8° 8′	7° 32′	6° 56′	6° 32′	5° 54′	5° 34′	5° 12′	4° 52′	4° 36′	4° 24′	4° 10′
12	15° 40′	12° 36′	10° 50′	9° 36′	8° 26′	7° 44′	6° 52′	6° 16′	5° 52′	5° 27′	5° 4′	4° 43′	4° 30′	4° 12′	4° 4′	3° 50′
13	14° 21′	11° 50′	9° 59′	8° 54′	7° 34′	7° 10′	6° 9′	5° 51′	5° 21′	5° 2′	4° 36′	4° 25′	4° 12′	3° 47′	3° 34′	3° 30′
14	12° 57′	10° 48′	9° 18′	8° 12′	7° 12′	6° 32′	5° 54′	5° 22′	5° 0′	4° 37′	4° 26′	4° 16′	4° 8′	3° 37′	3° 24′	3° 16′
16	11° 11′	9° 27′	8° 8′	7° 12′	6° 20′	5° 48′	5° 11′	4° 43′	4° 22′	4° 4′	3° 47′	3° 34′	3° 20′	3° 10′	3° 1′	2° 53′
18	9° 48′	8° 26′	7° 18′	6° 24′	5° 40′	5° 2′	4° 42′	4° 12′	3° 57′	3° 38′	3° 22′	3° 12′	3° 0′	2° 48′	2° 40′	2° 31′
20	8° 42′	7° 41′	6° 30′	5° 50′	5° 10′	4° 32′	4° 9′	3° 50′	3° 28′	3° 15′	2° 58′	2° 50′	2° 47′	2° 32′	2° 24′	2° 16′
22	8° 8′	6° 56′	5° 44′	5° 14′	4° 38′	4° 4′	3° 46′	3° 28′	3° 16′	2° 57′	2° 47′	2° 37′	2° 28′	2° 19′	2° 11′	2° 2′
24	7° 41′	6° 18′	5° 25′	4° 43′	4° 23′	3° 52′	3° 26′	3° 8′	2° 56′	2° 44′	2° 32′	2° 23′	2° 15′	2° 6′	2° 0′	1° 54′
26	7° 10′	5° 57′	5° 2′	4° 23′	3° 47′	3° 34′	3° 10′	2° 55′	2° 40′	2° 31′	2° 18′	2° 11′	2° 6′	1° 57′	1° 50′	1° 46′
28	6° 28′	5° 24′	4° 39′	4° 6′	3° 37′	3° 16′	2° 57′	2° 41′	2° 30′	2° 19′	2° 14′	2° 7′	1° 55′	1° 49′	1° 43′	1° 38′
30	5° 59′	5° 2′	4° 20′	3° 53′	3° 27′	3° 5′	2° 46′	2° 35′	2° 21′	2° 10′	2° 4′	1° 56′	1° 49′	1° 42′	1° 35′	1° 30′
32	5° 36′	4° 44′	4° 3′	3° 39′	3° 10′	2° 54′	2° 35′	2° 21′	2° 11′	2° 2′	1° 54′	1° 47′	1° 40′	1° 33′	1° 30′	1° 26′
36	4° 54′	4° 13′	3° 39′	3° 19′	2° 50′	2° 31′	2° 21′	2° 6′	1° 57′	1° 49′	1° 41′	1° 36′	1° 30′	1° 25′	1° 20′	1° 16′
40	4° 21′	3° 51′	3° 15′	2° 55′	2° 35′	2° 15′	2° 4′	1° 55′	1° 44′	1° 36′	1° 27′	1° 24′	1° 20′	1° 16′	1° 12′	1° 9′
48	3° 51′	3° 9′	2° 42′	2° 22′	2° 10′	2° 0′	1° 45′	1° 34′	1° 28′	1° 22′	1° 16′	1° 11′	1° 7′	1° 3′	1° 0′	0° 58′
60	2° 59′	2° 31′	2° 10′	1° 57′	1° 43′	1° 32′	1° 23′	1° 17′	1° 11′	1° 5′	1° 3′	0° 58′	0° 55′	0° 50′	0° 47′	0° 44′

TABLE NO. 5. **HELIX ANGLES** (Continued)

T.P.I.	Pitch Diameter (In Inches)															
	0·42	0·44	0·46	0·48	0·50	0·52	0·54	0·56	0·58	0·60	0·62	0·64	0·66	0·68	0·70	0·72
4	10° 54′	10° 21′	9° 54′	9° 36′	9° 20′	8° 51′	8° 28′	8° 12′	7° 54′	7° 36′	7° 24′	7° 10′	6° 54′	6° 48′	6° 30′	6° 21′
5	8° 44′	8° 17′	8° 0′	7° 40′	7° 20′	7° 4′	6° 48′	6° 30′	6° 18′	6° 5′	5° 52′	5° 44′	5° 34′	5° 21′	5° 11′	5° 4′
6	7° 16′	6° 57′	6° 37′	6° 24′	6° 12′	5° 53′	5° 38′	5° 24′	5° 15′	5° 4′	4° 52′	4° 43′	4° 36′	4° 24′	4° 21′	4° 13′
7	6° 12′	5° 59′	5° 40′	5° 27′	5° 12′	5° 4′	4° 50′	4° 38′	4° 31′	4° 25′	4° 15′	4° 6′	3° 58′	3° 50′	3° 42′	3° 37′
8	5° 28′	5° 11′	4° 57′	4° 48′	4° 40′	4° 26′	4° 14′	4° 6′	3° 57′	3° 48′	3° 42′	3° 35′	3° 27′	3° 21′	3° 15′	3° 10′
9	4° 48′	4° 36′	4° 24′	4° 14′	4° 4′	3° 55′	3° 44′	3° 35′	3° 29′	3° 22′	3° 16′	3° 10′	3° 5′	3° 0′	2° 54′	2° 49′
10	4° 20′	4° 10′	4° 0′	3° 50′	3° 40′	3° 32′	3° 24′	3° 15′	3° 9′	3° 2′	2° 57′	2° 52′	2° 47′	2° 41′	2° 36′	2° 32′
11	3° 59′	3° 46′	3° 39′	3° 28′	3° 18′	3° 13′	3° 6′	2° 56′	2° 53′	2° 47′	2° 41′	2° 36′	2° 31′	2° 26′	2° 22′	2° 18′
12	3° 38′	3° 16′	3° 14′	3° 12′	3° 2′	2° 55′	2° 49′	2° 42′	2° 36′	2° 32′	2° 26′	2° 22′	2° 18′	2° 14′	2° 10′	2° 6′
13	3° 21′	3° 4′	2° 59′	2° 55′	2° 48′	2° 42′	2° 36′	2° 29′	2° 26′	2° 19′	2° 15′	2° 12′	2° 8′	2° 4′	2° 0′	1° 53′
14	3° 6′	2° 52′	2° 47′	2° 42′	2° 36′	2° 30′	2° 25′	2° 19′	2° 14′	2° 10′	2° 6′	2° 2′	1° 58′	1° 55′	1° 51′	1° 48′
16	2° 41′	2° 30′	2° 28′	2° 24′	2° 18′	2° 11′	2° 7′	2° 3′	1° 58′	1° 54′	1° 51′	1° 48′	1° 44′	1° 41′	1° 39′	1° 35′
18	2° 24′	2° 15′	2° 11′	2° 7′	2° 3′	2° 0′	1° 55′	1° 49′	1° 45′	1° 41′	1° 38′	1° 35′	1° 32′	1° 30′	1° 27′	1° 24′
20	2° 11′	2° 5′	2° 0′	1° 55′	1° 50′	1° 46′	1° 42′	1° 38′	1° 34′	1° 30′	1° 27′	1° 25′	1° 23′	1° 21′	1° 18′	1° 16′
22	1° 57′	1° 53′	1° 48′	1° 43′	1° 39′	1° 35′	1° 31′	1° 28′	1° 26′	1° 24′	1° 20′	1° 17′	1° 15′	1° 13′	1° 11′	1° 9′
24	1° 50′	1° 43′	1° 39′	1° 35′	1° 31′	1° 28′	1° 25′	1° 21′	1° 18′	1° 16′	1° 13′	1° 11′	1° 9′	1° 7′	1° 5′	1° 3′
26	1° 40′	1° 35′	1° 31′	1° 27′	1° 24′	1° 21′	1° 18′	1° 15′	1° 13′	1° 10′	1° 7′	1° 4′	1° 3′	1° 1′	1° 0′	0° 58′
28	1° 34′	1° 30′	1° 26′	1° 22′	1° 18′	1° 16′	1° 12′	1° 9′	1° 7′	1° 5′	1° 3′	1° 1′	0° 59′	0° 57′	0° 56′	0° 53′
30	1° 26′	1° 20′	1° 18′	1° 16′	1° 13′	1° 10′	1° 8′	1° 6′	1° 4′	1° 1′	0° 59′	0° 57′	0° 55′	0° 53′	0° 52′	0° 50′
32	1° 21′	1° 17′	1° 15′	1° 12′	1° 8′	1° 6′	1° 3′	1° 1′	0° 59′	0° 58′	0° 56′	0° 54′	0° 53′	0° 51′	0° 49′	0° 47′
36	1° 12′	1° 7′	1° 5′	1° 3′	1° 1′	0° 59′	0° 57′	0° 55′	0° 53′	0° 51′	0° 50′	0° 48′	0° 46′	0° 44′	0° 43′	0° 42′
40	1° 5′	1° 1′	0° 59′	0° 57′	0° 55′	0° 52′	0° 50′	0° 49′	0° 48′	0° 47′	0° 45′	0° 43′	0° 42′	0° 40′	0° 39′	0° 38′
48	0° 55′	0° 52′	0° 49′	0° 47′	0° 45′	0° 43′	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 36′	0° 35′	0° 34′	0° 33′	0° 32′
60	0° 42′	0° 40′	0° 40′	0° 39′	0° 38′	0° 36′	0° 34′	0° 33′	0° 32′	0° 31′	0° 30′	0° 29′	0° 28′	0° 27′	0° 26′	0° 25′

TABLE NO. 6. **HELIX ANGLES (Continued)**

.I.	Pitch Diameter (In Inches) 0·74	0·76	0·78	0·80	0·82	0·84	0·86	0·88	0·90	0·92	0·94	0·96	0·98	1 in.	1·02	1·04
4	6° 11′	6° 0′	5° 52′	5° 41′	5° 36′	5° 27′	5° 19′	5° 11′	5° 2′	4° 56′	4° 53′	4° 50′	4° 46′	4° 41′	4° 33′	4° 25′
5	4° 55′	4° 48′	4° 40′	4° 31′	4° 25′	4° 22′	4° 15′	4° 8′	4° 3′	4° 0′	3° 53′	3° 47′	3° 44′	3° 40′	3° 36′	3° 32′
6	4° 8′	4° 0′	3° 54′	3° 49′	3° 44′	3° 38′	3° 32′	3° 28′	3° 23′	3° 18′	3° 13′	3° 10′	3° 7′	3° 6′	3° 1′	2° 55′
7	3° 31′	3° 25′	3° 20′	3° 16′	3° 11′	3° 6′	3° 2′	2° 59′	2° 54′	2° 50′	2° 47′	2° 43′	2° 39′	2° 36′	2° 34′	2° 32′
8	3° 5′	3° 0′	2° 56′	2° 52′	2° 48′	2° 44′	2° 40′	2° 35′	2° 31′	2° 28′	2° 27′	2° 25′	2° 23′	2° 20′	2° 16′	2° 13′
9	2° 44′	2° 40′	2° 36′	2° 32′	2° 28′	2° 24′	2° 20′	2° 18′	2° 16′	2° 12′	2° 10′	2° 7′	2° 4′	2° 2′	1° 59′	1° 56′
0	2° 28′	2° 24′	2° 20′	2° 16′	2° 12′	2° 10′	2° 7′	2° 4′	2° 2′	2° 0′	1° 57′	1° 55′	1° 53′	1° 50′	1° 48′	1° 46′
1	2° 15′	2° 11′	2° 7′	2° 5′	2° 1′	1° 59′	1° 57′	1° 54′	1° 51′	1° 49′	1° 46′	1° 44′	1° 41′	1° 39′	1° 38′	1° 37′
2	2° 4′	2° 2′	2° 0′	1° 55′	1° 51′	1° 49′	1° 46′	1° 43′	1° 40′	1° 38′	1° 36′	1° 35′	1° 35′	1° 33′	1° 29′	1° 27′
3	1° 49′	1° 47′	1° 46′	1° 45′	1° 42′	1° 40′	1° 38′	1° 36′	1° 34′	1° 32′	1° 30′	1° 28′	1° 26′	1° 24′	1° 22′	1° 21′
4	1° 45′	1° 42′	1° 40′	1° 38′	1° 35′	1° 33′	1° 31′	1° 29′	1° 27′	1° 25′	1° 23′	1° 21′	1° 19′	1° 18′	1° 17′	1° 15′
6	1° 33′	1° 30′	1° 28′	1° 25′	1° 23′	1° 21′	1° 19′	1° 18′	1° 16′	1° 15′	1° 14′	1° 12′	1° 11′	1° 9′	1° 7′	1° 6′
8	1° 22′	1° 20′	1° 18′	1° 16′	1° 14′	1° 12′	1° 11′	1° 9′	1° 8′	1° 7′	1° 5′	1° 3′	1° 2′	1° 1′	1° 0′	0° 59′
0	1° 14′	1° 12′	1° 10′	1° 8′	1° 6′	1° 5′	1° 3′	1° 2′	1° 1′	0° 59′	0° 58′	0° 57′	0° 56′	0° 55′	0° 54′	0° 53′
2	1° 7′	1° 6′	1° 4′	1° 3′	1° 1′	0° 59′	0° 58′	0° 57′	0° 56′	0° 54′	0° 53′	0° 52′	0° 51′	0° 50′	0° 50′	0° 49′
4	1° 1′	1° 0′	0° 58′	0° 57′	0° 56′	0° 55′	0° 54′	0° 52′	0° 50′	0° 49′	0° 48′	0° 47′	0° 46′	0° 45′	0° 45′	0° 44′
6	0° 57′	0° 56′	0° 55′	0° 53′	0° 51′	0° 50′	0° 49′	0° 48′	0° 47′	0° 47′	0° 46′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′
8	0° 53′	0° 52′	0° 51′	0° 50′	0° 48′	0° 47′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′	0° 39′	0° 38′	0° 38′
0	0° 49′	0° 48′	0° 47′	0° 45′	0° 44′	0° 43′	0° 43′	0° 41′	0° 40′	0° 40′	0° 39′	0° 38′	0° 37′	0° 36′	0° 35′	0° 35′
2	0° 46′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 36′	0° 35′	0° 35′	0° 34′	0° 34′	0° 33′
6	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 36′	0° 36′	0° 35′	0° 34′	0° 33′	0° 33′	0° 32′	0° 31′	0° 30′	0° 30′	0° 29′
0	0° 37′	0° 36′	0° 36′	0° 35′	0° 34′	0° 33′	0° 32′	0° 31′	0° 31′	0° 30′	0° 29′	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′
8	0° 31′	0° 30′	0° 29′	0° 29′	0° 28′	0° 28′	0° 27′	0° 26′	0° 25′	0° 24′	0° 24′	0° 23′	0° 23′	0° 22′	0° 22′	0° 22′
0	0° 24′	0° 24′	0° 23′	0° 22′	0° 22′	0° 21′	0° 21′	0° 20′	0° 20′	0° 20′	0° 19′	0° 19′	0° 18′	0° 18′	0° 17′	0° 17′

TABLE NO. 7. **HELIX ANGLES (Continued)**

T.P.I.	Pitch Diameter (In Inches) 1·06	1·08	1·10	1·12	1·14	1·16	1·18	1·20	1·22	1·24	1·26	1·28	1·30	1·32	1·34	1·36
4	4° 19′	4° 14′	4° 10′	4° 5′	4° 0′	3° 57′	3° 53′	3° 50′	3° 46′	3° 42′	3° 38′	3° 35′	3° 30′	3° 27′	3° 24′	3° 20′
5	3° 27′	3° 23′	3° 19′	3° 15′	3° 12′	3° 9′	3° 6′	3° 3′	3° 0′	2° 57′	2° 53′	2° 50′	2° 48′	2° 46′	2° 43′	2° 40′
6	2° 52′	2° 50′	2° 49′	2° 48′	2° 46′	2° 40′	2° 36′	2° 32′	2° 30′	2° 28′	2° 26′	2° 23′	2° 20′	2° 17′	2° 15′	2° 14′
7	2° 29′	2° 25′	2° 20′	2° 19′	2° 18′	2° 15′	2° 12′	2° 10′	2° 8′	2° 6′	2° 4′	2° 2′	2° 0′	1° 58′	2° 0′	1° 58′
8	2° 9′	2° 7′	2° 5′	2° 3′	2° 1′	1° 58′	1° 56′	1° 54′	1° 52′	1° 51′	1° 49′	1° 47′	1° 45′	1° 44′	1° 43′	1° 41′
9	1° 54′	1° 52′	1° 50′	1° 49′	1° 47′	1° 45′	1° 43′	1° 40′	1° 39′	1° 38′	1° 37′	1° 36′	1° 37′	1° 34′	1° 30′	1° 29′
10	1° 44′	1° 42′	1° 40′	1° 38′	1° 36′	1° 34′	1° 33′	1° 31′	1° 30′	1° 29′	1° 27′	1° 25′	1° 24′	1° 23′	1° 21′	1° 20′
11	1° 35′	1° 33′	1° 31′	1° 30′	1° 28′	1° 26′	1° 24′	1° 22′	1° 20′	1° 18′	1° 17′	1° 16′	1° 16′	1° 15′	1° 14′	1° 13′
12	1° 27′	1° 26′	1° 25′	1° 24′	1° 22′	1° 19′	1° 17′	1° 16′	1° 15′	1° 13′	1° 12′	1° 11′	1° 10′	1° 9′	1° 8′	1° 7′
13	1° 19′	1° 17′	1° 16′	1° 15′	1° 14′	1° 12′	1° 11′	1° 10′	1° 9′	1° 8′	1° 7′	1° 6′	1° 5′	1° 4′	1° 3′	1° 2′
14	1° 13′	1° 12′	1° 11′	1° 10′	1° 9′	1° 8′	1° 7′	1° 5′	1° 4′	1° 3′	1° 2′	1° 1′	1° 1′	1° 0′	0° 59′	0° 59′
16	1° 4′	1° 3′	1° 2′	1° 1′	1° 0′	0° 59′	0° 58′	0° 57′	0° 56′	0° 55′	0° 54′	0° 53′	0° 53′	0° 52′	0° 51′	0° 50′
18	0° 58′	0° 57′	0° 56′	0° 54′	0° 53′	0° 52′	0° 51′	0° 50′	0° 50′	0° 49′	0° 49′	0° 48′	0° 47′	0° 46′	0° 46′	0° 46′
20	0° 52′	0° 51′	0° 50′	0° 49′	0° 48′	0° 47′	0° 46′	0° 45′	0° 45′	0° 44′	0° 44′	0° 43′	0° 43′	0° 42′	0° 41′	0° 40′
22	0° 48′	0° 47′	0° 46′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 41′	0° 40′	0° 40′	0° 39′	0° 39′	0° 38′	0° 37′	0° 37′
24	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′	0° 38′	0° 38′	0° 37′	0° 37′	0° 36′	0° 36′	0° 35′	0° 35′	0° 34′	0° 34′
26	0° 40′	0° 39′	0° 38′	0° 37′	0° 37′	0° 36′	0° 35′	0° 35′	0° 35′	0° 34′	0° 34′	0° 33′	0° 33′	0° 32′	0° 31′	0° 31′
28	0° 37′	0° 37′	0° 36′	0° 35′	0° 35′	0° 34′	0° 33′	0° 33′	0° 32′	0° 32′	0° 31′	0° 31′	0° 30′	0° 30′	0° 30′	0° 30′
30	0° 34′	0° 34′	0° 33′	0° 32′	0° 32′	0° 31′	0° 31′	0° 30′	0° 30′	0° 30′	0° 29′	0° 29′	0° 28′	0° 28′	0° 28′	0° 28′
32	0° 33′	0° 32′	0° 31′	0° 31′	0° 30′	0° 30′	0° 29′	0° 29′	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 26′	0° 25′	0° 25′
36	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 26′	0° 25′	0° 25′	0° 24′	0° 24′	0° 24′	0° 23′	0° 23′	0° 23′	0° 22′	0° 21′
40	0° 26′	0° 25′	0° 25′	0° 25′	0° 24′	0° 24′	0° 23′	0° 22′	0° 22′	0° 22′	0° 21′	0° 21′	0° 21′	0° 21′	0° 20′	0° 20′
48	0° 21′	0° 21′	0° 21′	0° 20′	0° 20′	0° 20′	0° 19′	0° 19′	0° 18′	0° 18′	0° 18′	0° 17′	0° 17′	0° 17′	0° 17′	0° 17′
60	0° 17′	0° 17′	0° 16′	0° 16′	0° 16′	0° 16′	0° 15′	0° 15′	0° 15′	0° 15′	0° 15′	0° 14′	0° 14′	0° 14′	0° 14′	0° 14′

TABLE NO. 8. **HELIX ANGLES (Continued)**

Pitch Diameter (In Inches)

T.P.I.	1·38	1·40	1·42	1·44	1·46	1·48	1·50	1·55
4	3° 17′	3° 15′	3° 13′	3° 10′	3° 7′	3° 5′	3° 3′	2° 57′
5	2° 38′	2° 36′	2° 33′	2° 31′	2° 29′	2° 27′	2° 25′	2° 22′
6	2° 12′	2° 10′	2° 8′	2° 6′	2° 4′	2° 2′	2° 0′	1° 58′
7	1° 56′	1° 54′	1° 51′	1° 49′	1° 47′	1° 45′	1° 43′	1° 40′
8	1° 38′	1° 37′	1° 36′	1° 35′	1° 34′	1° 33′	1° 32′	1° 29′
9	1° 28′	1° 27′	1° 26′	1° 25′	1° 24′	1° 23′	1° 21′	1° 18′
10	1° 19′	1° 17′	1° 16′	1° 15′	1° 15′	1° 14′	1° 13′	1° 11′
11	1° 12′	1° 11′	1° 10′	1° 9′	1° 8′	1° 7′	1° 6′	1° 4′
12	1° 6′	1° 5′	1° 4′	1° 3′	1° 2′	1° 2′	1° 1′	0° 59′
13	1° 1′	1° 0′	0° 59′	0° 58′	0° 57′	0° 56′	0° 54′	0° 53′
14	0° 58′	0° 57′	0° 56′	0° 56′	0° 55′	0° 54′	0° 53′	0° 50′
16	0° 49′	0° 48′	0° 47′	0° 47′	0° 46′	0° 46′	0° 45′	0° 44′
18	0° 45′	0° 44′	0° 43′	0° 42′	0° 42′	0° 41′	0° 41′	0° 39′
20	0° 39′	0° 39′	0° 38′	0° 38′	0° 37′	0° 37′	0° 37′	0° 35′
22	0° 36′	0° 36′	0° 35′	0° 35′	0° 34′	0° 34′	0° 33′	0° 32′
24	0° 33′	0° 33′	0° 32′	0° 32′	0° 31′	0° 31′	0° 30′	0° 29′
26	0° 30′	0° 30′	0° 29′	0° 29′	0° 28′	0° 28′	0° 27′	0° 27′
28	0° 29′	0° 28′	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 26′
30	0° 27′	0° 27′	0° 26′	0° 26′	0° 26′	0° 25′	0° 25′	0° 24′
32	0° 24′	0° 24′	0° 24′	0° 23′	0° 23′	0° 23′	0° 22′	0° 21′
36	0° 21′	0° 21′	0° 21′	0° 21′	0° 20′	0° 20′	0° 20′	0° 20′
40	0° 19′	0° 19′	0° 19′	0° 19′	0° 18′	0° 18′	0° 18′	0° 17′
48	0° 17′	0° 17′	0° 16′	0° 16′	0° 16′	0° 15′	0° 15′	0° 14′
60	0° 14′	0° 14′	0° 13′	0° 13′	0° 13′	0° 13′	0° 12′	0° 12′

Pitch Diameter (In Inches)

T.P.I.	1·60	1·65	1·70	1·75	1·80	1·85	1·90	1·95
4	2° 51′	2° 46′	2° 39′	2° 36′	2° 31′	2° 27′	2° 24′	2° 20′
5	2° 17′	2° 14′	2° 9′	2° 5′	2° 2′	1° 58′	1° 55′	1° 53′
6	1° 54′	1° 51′	1° 47′	1° 44′	1° 41′	1° 39′	1° 37′	1° 33′
7	1° 37′	1° 34′	1° 30′	1° 28′	1° 26′	1° 24′	1° 23′	1° 20′
8	1° 25′	1° 22′	1° 21′	1° 19′	1° 17′	1° 15′	1° 12′	1° 10′
10	1° 8′	1° 7′	1° 5′	1° 2′	1° 0′	0° 59′	0° 58′	0° 56′
11	1° 2′	1° 0′	0° 59′	0° 57′	0° 55′	0° 53′	0° 52′	0° 51′
12	0° 58′	0° 56′	0° 54′	0° 52′	0° 50′	0° 49′	0° 48′	0° 47′
14	0° 48′	0° 47′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′
16	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 36′
18	0° 38′	0° 37′	0° 35′	0° 34′	0° 34′	0° 33′	0° 32′	0° 31′
20	0° 34′	0° 33′	0° 32′	0° 31′	0° 30′	0° 29′	0° 28′	0° 28′

TABLE NO. 8. **HELIX ANGLES (Continued)**

T.P.I.	Pitch Diameter (In Inches) 2 in.	2·05	2·10	2·15	2·20	2·25	2·30	2·35
4	2° 17′	2° 13′	2° 10′	2° 7′	2° 4′	2° 2′	1° 59′	1° 56′
5	1° 50′	1° 47′	1° 45′	1° 42′	1° 40′	1° 38′	1° 35′	1° 33′
6	1° 31′	1° 29′	1° 27′	1° 25′	1° 23′	1° 21′	1° 19′	1° 17′
7	1° 17′	1° 15′	1° 13′	1° 12′	1° 11′	1° 10′	1° 8′	1° 7′
8	1° 8′	1° 7′	1° 5′	1° 3′	1° 2′	1° 0′	0° 58′	0° 57′
10	0° 55′	0° 53′	0° 52′	0° 51′	0° 50′	0° 49′	0° 47′	0° 46′
11	0° 50′	0° 49′	0° 48′	0° 47′	0° 46′	0° 44′	0° 43′	0° 42′
12	0° 46′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′
14	0° 39′	0° 38′	0° 37′	0° 36′	0° 36′	0° 35′	0° 34′	0° 33′
16	0° 35′	0° 34′	0° 33′	0° 32′	0° 31′	0° 30′	0° 30′	0° 29′
18	0° 30′	0° 29′	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 26′
20	0° 27′	0° 26′	0° 26′	0° 25′	0° 25′	0° 25′	0° 24′	0° 23′

TABLE NO. 9. **HELIX ANGLES (Continued)**

T.P.I.	Pitch Diameter (In Inches) 2·40	2·45	2·50	2·55	2·60	2·65	2·70	2·75
4	1° 54′	1° 52′	1° 50′	1° 47′	1° 46′	1° 44′	1° 42′	1° 40′
5	1° 30′	1° 29′	1° 27′	1° 26′	1° 24′	1° 23′	1° 23′	1° 21′
6	1° 15′	1° 14′	1° 13′	1° 12′	1° 10′	1° 9′	1° 8′	1° 7′
7	1° 5′	1° 4′	1° 3′	1° 2′	1° 1′	0° 59′	0° 58′	0° 57′
8	0° 57′	0° 56′	0° 55′	0° 54′	0° 53′	0° 52′	0° 51′	0° 50′
10	0° 46′	0° 45′	0° 44′	0° 43′	0° 42′	0° 41′	0° 40′	0° 39′
11	0° 41′	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 37′	0° 36′
12	0° 38′	0° 37′	0° 36′	0° 35′	0° 35′	0° 34′	0° 34′	0° 33′
14	0° 32′	0° 32′	0° 31′	0° 31′	0° 30′	0° 29′	0° 29′	0° 28′
16	0° 29′	0° 28′	0° 28′	0° 27′	0° 26′	0° 26′	0° 25′	0° 25′
18	0° 25′	0° 25′	0° 24′	0° 24′	0° 23′	0° 23′	0° 22′	0° 22′
20	0° 23′	0° 22′	0° 22′	0° 22′	0° 21′	0° 21′	0° 20′	0° 20′

T.P.I.	Pitch Diameter (In Inches) 2·80	2·85	2·90	2·95	3·00	3·05	3·10	3·15
4	1° 38′	1° 36′	1° 34′	1° 33′	1° 31′	1° 30′	1° 29′	1° 27′
5	1° 19′	1° 18′	1° 17′	1° 15′	1° 13′	1° 12′	1° 11′	1° 10′
6	1° 5′	1° 4′	1° 3′	1° 2′	1° 1′	1° 0′	0° 59′	0° 58′
7	0° 56′	0° 55′	0° 54′	0° 53′	0° 52′	0° 52′	0° 51′	0° 50′
8	0° 49′	0° 48′	0° 47′	0° 46′	0° 45′	0° 45′	0° 44′	0° 43′
10	0° 39′	0° 38′	0° 38′	0° 37′	0° 37′	0° 36′	0° 35′	0° 35′
11	0° 35′	0° 35′	0° 34′	0° 34′	0° 33′	0° 33′	0° 32′	0° 32′
12	0° 32′	0° 32′	0° 31′	0° 31′	0° 31′	0° 30′	0° 30′	0° 29′
14	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 26′	0° 25′	0° 25′
16	0° 25′	0° 24′	0° 24′	0° 23′	0° 23′	0° 23′	0° 22′	0° 22′
18	0° 22′	0° 21′	0° 21′	0° 21′	0° 21′	0° 20′	0° 20′	0° 19′
20	0° 20′	0° 20′	0° 19′	0° 19′	0° 19′	0° 18′	0° 18′	0° 17′

TABLE NO. 9. **HELIX ANGLES (Continued)**

	Pitch Diameter (In Inches)							
T.P.I.	3·20	3·30	3·40	3·50	3·60	3·70	3·80	3·90
4	1° 25′	1° 22′	1° 20′	1° 18′	1° 16′	1° 14′	1° 13′	1° 12′
6	0° 57′	0° 56′	0° 54′	0° 52′	0° 51′	0° 49′	0° 48′	0° 46′
8	0° 42′	0° 41′	0° 40′	0° 39′	0° 38′	0° 37′	0° 37′	0° 36′
10	0° 34′	0° 33′	0° 32′	0° 31′	0° 30′	0° 29′	0° 28′	0° 28′
12	0° 28′	0° 28′	0° 27′	0° 27′	0° 26′	0° 25′	0° 24′	0° 23′
14	0° 25′	0° 24′	0° 23′	0° 22′	0° 22′	0° 21′	0° 20′	0° 20′
16	0° 21′	0° 20′	0° 20′	0° 19′	0° 19′	0° 19′	0° 18′	0° 18′

	Pitch Diameter (In Inches)							
T.P.I.	4·00	4·25	4·50	4·75	5·00	5·25	5·50	5·75
3	1° 31′	1° 24′	1° 20′	1° 16′	1° 14′	1° 12′	1° 11′	1° 9′
4	1° 8′	1° 4′	1° 1′	0° 58′	0° 55′	0° 52′	0° 49′	0° 47′
5	0° 54′	0° 53′	0° 50′	0° 47′	0° 44′	0° 42′	0° 40′	0° 38′
6	0° 45′	0° 42′	0° 40′	0° 38′	0° 37′	0° 36′	0° 36′	0° 35′
8	0° 34′	0° 32′	0° 30′	0° 29′	0° 27′	0° 26′	0° 25′	0° 24′
10	0° 27′	0° 26′	0° 24′	0° 23′	0° 22′	0° 21′	0° 20′	0° 19′
14	0° 20′	0° 18′	0° 17′	0° 17′	0° 16′	0° 15′	0° 14′	0° 14′

	Pitch Diameter (In Inches)							
T.P.I.	6·00	6·25	6·50	6·75	7·00	7·25	7·50	8·00
2	1° 32′	1° 26′	1° 24′	1° 22′	1° 20′	1° 18′	1° 13′	1° 8′
3	1° 8′	1° 5′	1° 1′	0° 57′	0° 52′	0° 50′	0° 48′	0° 43′
4	0° 46′	0° 43′	0° 42′	0° 41′	0° 40′	0° 38′	0° 36′	0° 34′
5	0° 36′	0° 35′	0° 34′	0° 33′	0° 32′	0° 30′	0° 28′	0° 27′
6	0° 34′	0° 32′	0° 30′	0° 28′	0° 26′	0° 25′	0° 24′	0° 22′
8	0° 23′	0° 22′	0° 21′	0° 20′	0° 20′	0° 19′	0° 18′	0° 17′
10	0° 18′	0° 17′	0° 16′	0° 16′	0° 16′	0° 15′	0° 14′	0° 13′

TABLE NO. 10

BRITISH STANDARD WHITWORTH THREADS—ELEMENTS AND BASIC SIZES

Nominal Diameter	T.P.I.	Pitch	Diameters			Helix Angle	Depth	
			Major	Minor	Effective		Angular	Actual
in.			in.	in.	in.		in.	in.
$\frac{1}{4}$	20	0·050 00	0·2500	0·1860	0·2180	4° 10′	0·048 03	0·032 02
$\frac{5}{16}$	18	0·055 56	0·3125	0·2414	0·2769	3° 35′	0·053 36	0·035 57
$\frac{3}{8}$	16	0·062 50	0·3750	0·2950	0·3350	3° 24′	0·060 03	0·040 02
$\frac{7}{16}$	14	0·071 43	0·4375	0·3460	0·3918	3° 19′	0·068 61	0·045 74
$\frac{1}{2}$	12	0·083 33	0·5000	0·3933	0·4466	3° 24′	0·080 04	0·053 36
$\frac{9}{16}$	12	0·083 33	0·5625	0·4558	0·5091	2° 58′	0·080 04	0·053 36
$\frac{5}{8}$	11	0·090 91	0·6250	0·5086	0·5668	2° 55′	0·087 32	0·058 21
$\frac{11}{16}$	11	0·090 91	0·6875	0·5711	0·6293	2° 54′	0·087 32	0·058 21
$\frac{3}{4}$	10	0·100 00	0·7500	0·6219	0·6860	2° 39′	0·096 05	0·064 03
$\frac{13}{16}$	10	0·100 00	0·8125	0·6844	0·7485	2° 24′	0·096 05	0·064 03
$\frac{7}{8}$	9	0·111 11	0·8750	0·7327	0·8039	2° 31′	0·106 72	0·071 15
$\frac{15}{16}$	9	0·111 11	0·9375	0·7952	0·8664	2° 15′	0·106 72	0·071 15
1	8	0·125 00	1·0000	0·8399	0·9200	2° 25′	0·120 06	0·080 04
$1\frac{1}{8}$	7	0·142 86	1·1250	0·9420	1·0335	2° 28′	0·137 21	0·091 47
$1\frac{1}{4}$	7	0·142 86	1·2500	1·0670	1·1585	2° 15′	0·137 21	0·091 47
$1\frac{3}{8}$	6	0·166 67	1·3750	1·1616	1·2683	2° 21′	0·160 08	0·106 72
$1\frac{1}{2}$	6	0·166 67	1·5000	1·2866	1·3933	2° 9′	0·160 08	0·106 72
$1\frac{5}{8}$	5	0·200 00	1·6250	1·3689	1·4969	2° 24′	0·192 10	0·128 07
$1\frac{3}{4}$	5	0·200 00	1·7500	1·4939	1·6219	2° 16′	0·192 10	0·128 07
2	4·5	0·222 22	2·0000	1·7154	1·8577	2° 10′	0·213 44	0·142 30
$2\frac{1}{4}$	4	0·250 00	2·2500	1·9298	2·0899	2° 9′	0·240 12	0·160 08
$2\frac{1}{2}$	4	0·250 00	2·5000	2·1798	2·3399	1° 58′	0·240 12	0·160 08
$2\frac{3}{4}$	3·5	0·285 71	2·7500	2·3841	2·5670	2° 1′	0·274 42	0·182 93
3	3·5	0·285 71	3·0000	2·6341	2·8170	1° 49′	0·274 42	0·182 93
$3\frac{1}{4}$	3·25	0·307 69	3·2500	2·8560	3·0530	1° 51′	0·295 60	0·197 00
$3\frac{1}{2}$	3·25	0·307 69	3·5000	3·1060	3·3030	1° 43′	0·295 60	0·197 00
$3\frac{3}{4}$	3	0·333 33	3·7500	3·3231	3·5366	1° 41′	0·320 16	0·213 43
4	3	0·333 33	4·0000	3·5731	3·7866	1° 37′	0·320 16	0·213 43
$4\frac{1}{2}$	2·875	0·347 83	4·5000	4·0546	4·2773	1° 28′	0·345 08	0·222 70
5	2·75	0·363 64	5·0000	4·5343	4·7672	1° 22′	0·349 28	0·232 90
$5\frac{1}{2}$	2·625	0·380 95	5·5000	5·0121	5·2561	1° 20′	0·365 58	0·243 95
6	2·5	0·400 00	6·0000	5·4877	5·7439	1° 16′	0·384 20	0·256 14

B.S.W. Thread Proportions. See Fig. 123.

$$\text{Angle} = 55^\circ$$

$$\text{Actual depth } (d) = 0{\cdot}640327\, P$$

$$= 2/3\, h$$

$$\text{Angular depth } (h) = 0{\cdot}960491\, P$$

$$\text{Shortening } (t) = \frac{h}{6} = 0{\cdot}160083\, P$$

$$\text{Radius } (r) = 0{\cdot}137329\, P$$

$$\text{Depth of rounding } (y) = 0{\cdot}073917\, P$$

$$= r - r \cos 62\tfrac{1}{2}^\circ$$

These proportions apply to all threads of Whitworth form, including B.S.W., B.S.F., B.S.P. (both Parallel and Taper), and Whitworth screw threads of special diameters, pitches, and lengths of engagement.

TABLE NO. 11

BRITISH STANDARD WHITWORTH THREADS—USEFUL DATA

T.P.I.	Radius	Depth of Rounding	Shortening	Best-size Wire	Pitch
	in.	in.	in.	in.	in.
60	0·002 29	0·001 23	0·002 67	0·009 39	0·016 67
48	0·002 86	0·001 54	0·003 33	0·011 74	0·020 83
40	0·003 43	0·001 85	0·004 00	0·014 10	0·025 00
36	0·003 81	0·002 05	0·004 45	0·015 66	0·027 78
32	0·004 29	0·002 31	0·005 00	0·017 61	0·031 25
28	0·004 90	0·002 64	0·005 72	0·020 13	0·035 71
26	0·005 28	0·002 84	0·006 16	0·021 68	0·038 46
24	0·005 72	0·003 08	0·006 67	0·023 45	0·041 67
22	0·006 24	0·003 36	0·007 28	0·025 62	0·045 46
20	0·006 87	0·003 70	0·008 00	0·028 18	0·050 00
19	0·007 73	0·003 89	0·008 42	0·029 67	0·052 63
18	0·007 63	0·004 11	0·008 89	0·031 32	0·055 56
16	0·008 58	0·004 62	0·010 00	0·035 23	0·062 50
14	0·009 81	0·005 28	0·011 43	0·040 26	0·071 43
12	0·011 44	0·006 16	0·013 34	0·046 97	0·083 33
11	0·012 48	0·006 72	0·014 55	0·051 24	0·090 91
10	0·013 73	0·007 39	0·016 01	0·056 37	0·100 00
9	0·015 26	0·008 21	0·017 79	0·062 63	0·111 11
8	0·017 17	0·009 24	0·020 01	0·070 46	0·125 00
7	0·019 62	0·010 56	0·022 87	0·080 53	0·142 86
6	0·022 89	0·012 32	0·026 68	0·093 95	0·166 67
5	0·027 47	0·014 78	0·032 02	0·112 74	0·200 00
4½	0·030 52	0·016 43	0·035 57	0·125 27	0·222 22
4	0·034 33	0·018 48	0·040 02	0·140 92	0·250 00
3½	0·039 24	0·021 12	0·045 74	0·161 05	0·285 71
3¼	0·042 26	0·022 74	0·049 26	0·173 44	0·307 69
3	0·045 78	0·024 64	0·053 36	0·187 90	0·333 33
2⅞	0·047 77	0·025 71	0·055 68	0·196 07	0·347 83
2¾	0·049 94	0·026 88	0·058 21	0·204 98	0·363 64
2⅝	0·052 32	0·028 16	0·060 98	0·214 74	0·380 95
2½	0·054 93	0·029 57	0·064 03	0·225 48	0·400 00

Radius = 0·137329 P. Depth of rounding = 0·073917 P.
Shortening = $\frac{1}{6}$ × Angular depth = 0·160083 P. Angular depth = 0·960495 P
It should be noted that in the above table and in others that follow, the *best-size wire diameters* have been calculated *disregarding the helix angles*. The basic thread form is shown in Fig. 123.

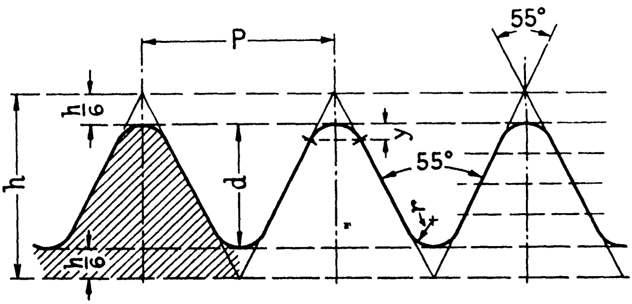

FIG. 123. B.S.W. THREAD SECTION

TABLE NO. 12

BRITISH STANDARD PIPE THREADS (PARALLEL)

Elements and Basic Sizes

B.S.P. SIZE	T.P.I.	PITCH	DIAMETERS			HELIX ANGLE	DEPTHS	
			MAJOR	MINOR	EFFECTIVE		ANGULAR	ACTUAL
in.		in.	in.	in.	in.		in.	in.
1/8	28	0·035 71	0·3830	0·3372	0·3601	1° 49′	0·034 31	0·022 87
1/4	19	0·052 63	0·5180	0·4506	0·4843	1° 59′	0·050 55	0·033 70
3/8	19	0·052 63	0·6560	0·5886	0·6223	1 33′	0·050 55	0·033 70
1/2	14	0·071 43	0·8250	0·7336	0·7793	1° 40′	0·068 61	0·045 74
5/8	14	0·071 43	0·9020	0·8106	0·8563	1° 30′	0·068 61	0·045 74
3/4	14	0·071 43	1·0410	0·9496	0·9953	1° 19′	0·068 61	0·045 74
7/8	14	0·071 43	1·1890	1·0976	1·1433	1° 9′	0·068 61	0·045 74
1	11	0·090 91	1·3090	1·1926	1·2508	1° 18′	0·087 32	0·058 21
1 1/4	11	0·090 91	1·6500	1·5336	1·5918	1° 3′	0·087 32	0·058 21
1 1/2	11	0·090 91	1·8820	1·7656	1·8238	0° 54′	0·087 32	0·058 21
1 3/4	11	0·090 91	2·1160	1·9996	2·0578	0° 48′	0·087 32	0·058 21
2	11	0·090 91	2·3470	2·2306	2·2888	0° 43′	0·087 32	0·058 21
2 1/4	11	0·090 91	2·5870	2·4706	2·5288	0° 39′	0·087 32	0·058 21
2 1/2	11	0·090 91	2·9600	2·8436	2·9018	0° 29′	0·087 32	0·058 21
2 3/4	11	0·090 91	3·2100	3·0936	3·1518	0° 31′	0·087 32	0·058 21
3	11	0·090 91	3·4600	3·3436	3·4018	0 30′	0·087 32	0·058 21

NOTES

(1) For *depth of rounding*, *radius*, and *best-wire diameter* applicable to any pitch in the table given above, see Table No. 11.

(2) British Standard Pipe (B.S.P.) Parallel Threads are included in B.S. No. 84, which relates to parallel screw threads with the Whitworth form. The parallel pipe series was included on account of its extensive use in engineering practice for general constructional purposes where a parallel thread of finer pitch than the B.S.F. series is required.

TABLE NO. 13

BRITISH STANDARD FINE SCREW THREADS
Elements and Basic Sizes

Nom. Dia.	T.P.I.	Pitch	Diameters (in.)			Helix Angle	Depths	
			Major	Minor	Effective		Angular	Actual
in.		in.	in.	in.	in.		in.	in.
1/4	26	0·038 76	0·250 0	0·200 7	0·225 4	3° 7′	0·036 942	0·024 628
5/16	22	0·045 45	0·312 5	0·254 3	0·283 4	2° 54′	0·043 659	0·029 106
3/8	20	0·050 00	0·375 0	0·311 0	0·343 0	2° 33′	0·048 025	0·032 017
7/16	18	0·055 56	0·437 5	0·366 4	0·401 9	2° 21′	0·053 361	0·035 574
1/2	16	0·062 50	0·500 0	0·420 0	0·460 0	2° 29′	0·060 031	0·040 021
9/16	16	0·062 50	0·562 5	0·482 5	0·522 5	2° 10′	0·060 031	0·040 021
5/8	14	0·071 43	0·625 0	0·533 5	0·579 3	2° 14′	0·068 607	0·045 737
11/16	14	0·071 43	0·687 5	0·596 0	0·641 8	2° 2′	0·068 607	0·045 737
3/4	12	0·083 33	0·750 0	0·643 3	0·696 6	2° 11′	0·080 041	0·053 361
13/16	12	0·083 33	0·812 5	0·705 8	0·759 1	2° 2′	0·080 041	0·053 361
7/8	11	0·090 91	0·875 0	0·758 6	0·816 8	2° 6′	0·087 32	0·058 21
1″	10	0·100 00	1·000 0	0·871 9	0·936 0	2° 3′	0·096 05	0·064 03
1 1/8	9	0·111 11	1·125 0	0·982 7	1·053 9	1° 56′	0·106 72	0·071 15
1 1/4	9	0·111 11	1·250 0	1·107 7	1·178 9	1° 54′	0·106 72	0·071 15
1 3/8	8	0·125 00	1·375 0	1·214 9	1·295 0	1° 52′	0·120 06	0·080 04
1 1/2	8	0·125 00	1·500 0	1·339 9	1·420 0	1° 44′	0·120 06	0·080 04
1 5/8	8	0·125 00	1·625 0	1·464 9	1·545 0	1° 37′	0·120 06	0·080 04
1 3/4	7	0·142 86	1·750 0	1·567 0	1·658 5	1° 42′	0·137 21	0·091 47
2″	7	0·142 86	2·000 0	1·817 0	1·908 5	1° 30′	0·137 21	0·091 47
2 1/4	6	0·166 67	2·250 0	2·036 6	2·143 3	1° 32′	0·160 08	0·106 72
2 1/2	6	0·166 67	2·500 0	2·286 6	2·393 3	1° 21′	0·160 08	0·106 72
2 3/4	6	0·166 67	2·750 0	2·536 6	2·643 3	1° 6′	0·160 08	0·106 72
3″	5	0·200 00	3·000 0	2·743 9	2·871 9	1° 24′	0·192 10	0·128 07

Notes

(1) For *depth of rounding, radius,* and *best-wire diameter* applicable to any pitch in the table given above, see Table No. 11.

(2) The form of thread used on B.S.F. screws is the same as that used on B.S.W. screws and shown in Fig. 123. The B.S.F. thread series is used where finer pitches are required than those listed in relation to the diameters shown in the B.S.W. table (see Table No. 10). Fine pitches facilitate small axial adjustments. Diameters shown in the table above are those most commonly used. B.S. No. 84 gives diameters from 3/16 in. to 4¼ in. For diameters above 4¼ in. the B.S.I. recommend that 4 T.P.I. be used.

TABLE NO. 14

BRITISH ASSOCIATION THREADS—ELEMENTS AND BASIC SIZES

B.A. No.	T.P.I.	Pitch		Major Dia.		Effective Dia.		Minor Dia.	
		mm.	in.	mm.	in.	mm.	in.	mm.	in.
0	25·4	1·00	0·0394	6·0	0·2362	5·40	0·2126	4·80	0·1890
1	28·2	0·90	0·0354	5·3	0·2087	4·76	0·1874	4·22	0·1661
2	31·4	0·81	0·0319	4·7	0·1850	4·215	0·1659	3·73	0·1468
3	34·8	0·73	0·0287	4·1	0·1614	3·66	0·1442	3·22	0·1269
4	38·5	0·66	0·0260	3·6	0·1417	3·205	0·1261	2·81	0·1106
5	43·0	0·59	0·0232	3·2	0·1260	2·845	0·1120	2·49	0·0981
6	47·9	0·53	0·0209	2·8	0·1102	2·48	0·0977	2·16	0·0852
7	52·9	0·48	0·0189	2·5	0·0984	2·21	0·0871	1·92	0·0758
8	59·1	0·43	0·0169	2·2	0·0866	1·94	0·0765	1·68	0·0663
9	65·1	0·39	0·0154	1·9	0·0748	1·665	0·0656	1·43	0·0564
10	72·6	0·35	0·0138	1·7	0·0669	1·49	0·0587	1·28	0·0504
11	81·9	0·31	0·0122	1·5	0·0591	1·315	0·0445	1·13	0·0443
12	90·9	0·28	0·0110	1·3	0·0511	1·13	0·0379	0·96	0·0378
13	102	0·25	0·0098	1·2	0·0472	1·05	0·0354	0·90	0·0352
14	109·9	0·23	0·0091	1·0	0·0394	0·86	0·0284	0·72	0·0280
15	120·5	0·21	0·0083	0·9	0·0354	0·775	0·0254	0·65	0·0250

B.A. No.	Helix Angle	Depth of Thread		Radius	Depth of Rounding	Best-size Cylinder	B.A. No.
		Angular (in.)	Actual (in.)	(in.)	(in.)	(in.)	
0	3° 23′	0·0447	0·0236	0·0072	0·0043	0·0217	0
1	3° 27′	0·0402	0·0213	0·0064	0·0039	0·0195	1
2	3° 30′	0·0363	0·0191	0·0058	0·0035	0·0175	2
3	3° 38′	0·0327	0·0172	0·0052	0·0031	0·0158	3
4	3° 45′	0·0294	0·0156	0·0047	0·0028	0·0143	4
5	3° 46′	0·0264	0·0139	0·0042	0·0026	0·0128	5
6	3° 54′	0·0237	0·0125	0·0038	0·0023	0·0115	6
7	3° 57′	0·0216	0·0112	0·0034	0·0021	0·0104	7
8	4° 2′	0·0192	0·0102	0·0031	0·0019	0·0093	8
9	4° 16′	0·0172	0·0092	0·0028	0·0016	0·0084	9
10	4° 17′	0·0156	0·0083	0·0025	0·0015	0·0076	10
11	4° 18′	0·0139	0·0073	0·0022	0·0014	0·0067	11
12	4° 31′	0·0125	0·0066	0·0020	0·0012	0·0060	12
13	4° 20′	0·0112	0·0059	0·0018	0·0011	0·0055	13
14	4° 54′	0·0102	0·0055	0·0016	0·0010	0·0050	14
15	4° 59′	0·0092	0·0050	0·0015	0·0009	0·0045	15

For basic thread form, see Fig. 124.

British Association (B.A.) Thread Proportions. See Fig. 124.

Angle $= 47\frac{1}{2}°$
Actual depth $(d) = 0{\cdot}6\ P$
Angular depth $(h) = 1{\cdot}13633\ P$
Shortening $(t) = 0{\cdot}236\ D = 0{\cdot}268\ P$
Radius $(r) = \dfrac{2\ P}{11} = 0{\cdot}18\ P$ (approx.)
Pitch (P), usually given in mm.

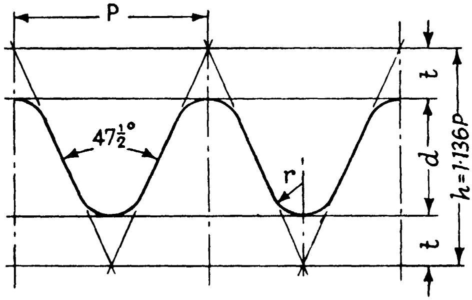

FIG. 124. B.A. THREAD SECTION

B.A. sizes are tabulated from 0 to 25, but Nos. 0 to 10 are those in most general use. The B.S.I. recommend that B.A. threads be used for screws below $\frac{1}{4}$ in. diameter, but suggest that where B.S.F. threads are being used it is preferable to use a 7/32 in. B.S.F. thread, although

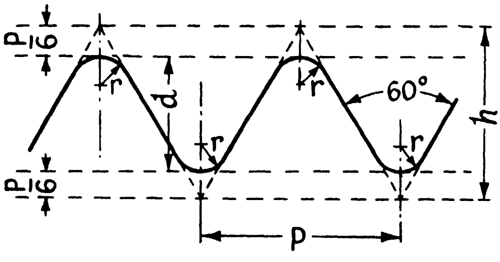

FIG. 125. B.S.C. THREAD SECTION

it is smaller than a No. 0. B.A. thread. B.S. No. 93 deals with B.A. threads and includes limits for screws and nuts.

British Standard Cycle (B.S.C.) Thread Proportions. See Fig. 125.

Angle $= 60°$
Actual depth $(d) = 0{\cdot}5327\ P$
Angular depth $(h) = 0{\cdot}866\ P$
Shortening $(t) = \frac{1}{6}\ P$
Radius $(r) = \frac{1}{6}\ P$

Prior to its standardization by the B.S.I. in 1938, this thread was known as the Cycle Engineers', or C.E.I., thread. It is largely used in cycle and motor-cycle work but the B.S.I. deprecate any extension of its use by employing it for general engineering work. "Any tendency to introduce the B.S.C. thread into general engineering would inevitably result in confusion due to the visual resemblance to, but lack of interchangeability with, threads of Whitworth or B.A. form." (B.S. 93.)

METRIC SCREW THREADS—SYSTÈME INTERNATIONAL (S.I.)

B.S. No. 1095 : 1943 covers this thread system but the Institution

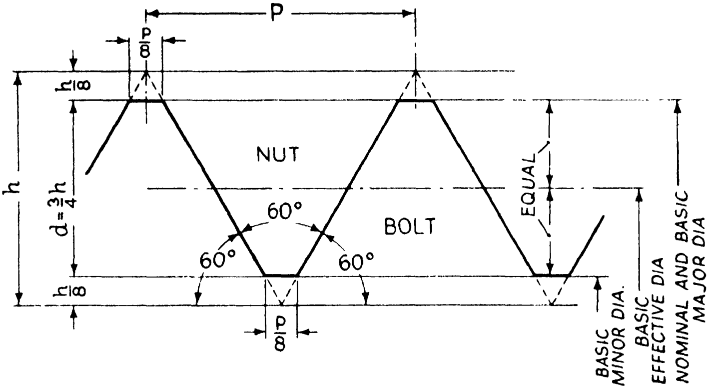

FIG. 126. BASIC FORM OF METRIC (S.I.) THREADS

Angular depth of thread (h) = $0{\cdot}8660 \times P$
Basic depth of engagement (d) = $\frac{3}{4} h = 0{\cdot}6495\,P$
Basic effective dia. = nominal basic major dia. — $0{\cdot}6495\,P$
Basic minor dia. = Nominal basic major dia. — $1{\cdot}2990\,P$

recommends that in British practice no departures be made from present uses of Whitworth and B.A. threads in favour of metric threads. B.S. No. 1095 does not supersede the specifications on sparking plug threads (Nos. B.S. 45 and B.S. 2E. 9).

The basic form of Metric (S.I.) threads is given in Fig. 126. As will be seen from Table No. 15 the principal series of S.I. threads starts with a diameter of 6 mm, associated with a pitch of 1 mm. Up to, and including the 80 mm size, the diameters and their related pitches in this table are identical with those fixed by the International Conference in Zurich in 1898, with the exception of the pitches for the 72, 76, and 80 mm threads which were 6·5, 6·5, and 7 mm, respectively, instead of the uniform pitch of 6 mm given in the table. These modifications have been adopted, however, by all countries using the S.I. threads.

Above 80 mm the French standard series (CNM 3) and the Swiss standard series (V.S.M. 12004) progress in steps of 5 mm on diameter. The German standard series (DIN 14), however, continues with 84 and then progresses in 5 mm steps, thus 89, 94, 99, etc.

All countries adopt a uniform pitch of 6 mm above 60 mm.

TABLE NO. 15

METRIC SCREW THREADS—SYSTÈME INTERNATIONAL (S.I.)

(Standard Series given in B.S. 1095: 1943. Reproduced by permission)

Major Dia. (Nominal and Basic) mm	Pitch p mm	Effective Dia. (Basic) mm	Minor Dia. (Basic) mm	Depth of Thread (Basic) h mm
6	1	5·350	4·700	0·650
7	1	6·350	5·700	0·650
8	1·25	7·188	6·376	0·812
9	1·25	8·188	7·376	0·812
10	1·5	9·026	8·052	0·974
11	1·5	10·026	9·052	0·974
12	1·75	10·863	9·726	1·137
14	2	12·701	11·402	1·229
16	2	14·701	13·402	1·229
18	2·5	15·376	14·752	1·624
20	2·5	18·376	16·752	1·624
22	2·5	20·376	18·752	1·624
24	3	22·051	20·102	1·949
27	3	25·051	23·102	1·949
30	3·5	27·727	25·454	2·273
33	3·5	30·727	28·454	2·273
36	4	33·402	30·804	2·598
39	4	36·402	33·804	2·598
42	4·5	39·077	36·154	2·923
45	4·5	42·077	39·154	2·923
48	5	44·752	41·504	3·248
52	5	48·752	45·504	3·248
56	5·5	52·428	48·856	3·572
60	5·5	56·428	52·856	3·572
64	6	60·103	56·206	3·897
68	6	64·103	60·206	3·897
72	6	68·103	64·206	3·897
76	6	72·103	68·206	3·897
80	6	76·103	72·206	3·897
85	6	81·103	77·206	3·897
90	6	86·103	82·206	3·897
95	6	91·103	87·206	3·897
100	6	96·103	92·206	3·897
105	6	101·103	97·206	3·897
110	6	106·103	102·206	3·897
115	6	111·103	107·206	3·897
120	6	116·103	112·206	3·897
125	6	121·103	117·206	3·897
etc., in steps of 5 mm				

Diameters Below 6 mm. In continental countries there are differences in the tabulation of standard diameters and pitches of metric threads below 6 mm.

DIAMETER (mm.)	1·0	1·2	1·4	1·6	1·7	1·8	2·0	2·2	2·3	2·5	2·6	3	3·5	4	4·5	5·0	5·5
PITCH (mm.) German and Swiss	0·25	0·25	0·3	—	0·35	—	0·4	—	0·4	—	0·45	0·5	0·6	0·7	0·75	0·8	0·9
PITCH (mm.) French	0·25	0·25	0·3	0·3	—	0·4	0·4	0·45	—	0·45	—	0·6	0·6	0·75	0·75	0·9	0·9

AMERICAN NATIONAL THREADS

$$H = \text{Basic depth} = 0{\cdot}649519\,P$$
$$F = 0{\cdot}125\,P$$
$$\text{Angle} = 60^\circ$$

(Symbols in Fig. 127 are those used by B.S.I. See Table No. 16.)

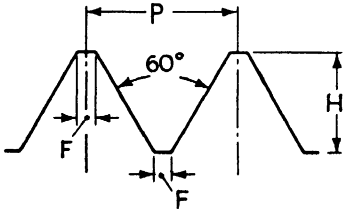

FIG. 127. AMERICAN NATIONAL THREAD

Classification and Tolerances. The American specification establishes four distinct classes of screw thread fits for general use, these are—

Class 1 fit Includes screw-thread work in which the threads must assemble readily.

Class 2 fit Includes the major portion of interchangeable screw thread work, finished and semi-finished bolts and nuts, machine screws, etc.

Class 3 fit Includes the highest grade of interchangeable screw-threaded work.

Class 4 fit Includes screw-thread work requiring a fine snug fit, somewhat closer than class 3. In this class of fit selective assembly may be necessary.

Limits and Tolerances. It is emphasized in B.S. 1104, from which the following notes are reproduced, that a single class of fit is established for Acme screw threads.

The basic diameters are—

1. Maximum major diameter of screw.
2. Effective diameter (max. of screw = min. of nut).
3. Minimum minor diameter of nut.

TABLE NO. 16

AMERICAN NATIONAL COARSE (N.C.) THREAD SERIES

Tables No. 16 and 17 are reproduced from the B.S. Handbook No. 2, by permission

IDENTIFICATION		BASIC DIAMETERS			THREAD DATA			
Size	Threads per in.	Major diameter	Effective diameter	Minor diameter	Pitch	Depth of thread	Basic width of flat	Minimum width of flat at major diameter of nut
	n	D	E	K	p	h	$p/8$	$p/24$
		in.	in.	in.	in.	in.	in.	in.
1	64	0·073	0·062 9	0·052 7	0·015 62	0·010 15	0·001 95	0·000 65
2	56	0·086	0·074 4	0·062 8	0·017 86	0·011 60	0·002 23	0·000 74
3	48	0·099	0·085 5	0·071 9	0·020 83	0·013 53	0·002 60	0·000 87
4	40	0·112	0·095 8	0·079 5	0·025 00	0·016 24	0·003 12	0·001 04
5	40	0·125	0·108 8	0·092 5	0·025 00	0·016 24	0·003 12	0·001 04
6	32	0·138	0·117 7	0·097 4	0·031 25	0·020 30	0·003 91	0·001 30
8	32	0·164	0·143 7	0·123 4	0·031 25	0·020 30	0·003 91	0·001 30
10	24	0·190	0·162 9	0·135 9	0·041 67	0·027 06	0·005 21	0·001 74
12	24	0·216	0·188 9	0·161 9	0·041 67	0·027 06	0·005 21	0·001 74
$\frac{1}{4}$	20	0·250 0	0·217 5	0·185 0	0·050 00	0·032 48	0·006 25	0·002 08
$\frac{5}{16}$	18	0·312 5	0·276 4	0·240 3	0·055 56	0·036 08	0·006 94	0·002 31
$\frac{3}{8}$	16	0·375 0	0·334 4	0·293 8	0·062 50	0·040 59	0·007 81	0·002 60
$\frac{7}{16}$	14	0·437 5	0·391 1	0·344 7	0·071 43	0·046 39	0·008 93	0·002 98
$\frac{1}{2}$	13	0·500 0	0·450 0	0·400 1	0·076 92	0·049 96	0·009 62	0·003 21
$\frac{9}{16}$	12	0·562 5	0·508 4	0·454 2	0·083 33	0·054 13	0·010 42	0·003 47
$\frac{5}{8}$	11	0·625 0	0·566 0	0·506 9	0·090 91	0·059 05	0·011 36	0·003 79
$\frac{3}{4}$	10	0·750 0	0·685 0	0·620 1	0·100 00	0·064 95	0·012 50	0·004 17
$\frac{7}{8}$	9	0·875 0	0·802 8	0·730 7	0·111 11	0·072 17	0·013 89	0·004 63
1	8	1·000 0	0·918 8	0·837 6	0·125 00	0·081 19	0·015 62	0·005 21
$1\frac{1}{8}$	7	1·125 0	1·032 2	0·939 4	0·142 86	0·092 79	0·017 86	0·005 95
$1\frac{1}{4}$	7	1·250 0	1·157 2	1·064 4	0·142 86	0·092 79	0·017 86	0·005 95
$1\frac{3}{8}$	6	1·375 0	1·266 7	1·158 5	0·166 67	0·108 25	0·020 83	0·006 94
$1\frac{1}{2}$	6	1·500 0	1·391 7	1·283 5	0·166 67	0·108 25	0·020 83	0·006 94
$1\frac{3}{4}$	5	1·750 0	1·620 1	1·490 2	0·200 00	0·129 90	0·025 00	0·008 33
2	$4\frac{1}{2}$	2·000 0	1·855 7	1·711 3	0·222 22	0·144 34	0·027 78	0·009 26
$2\frac{1}{4}$	$4\frac{1}{2}$	2·250 0	2·105 7	1·961 3	0·222 22	0·144 34	0·027 78	0·009 26
$2\frac{1}{2}$	4	2·500 0	2·337 6	2·175 2	0·250 00	0·162 38	0·031 25	0·010 42
$2\frac{3}{4}$	4	2·750 0	2·587 6	2·425 2	0·250 00	0·162 38	0·031 25	0·010 42
3	4	3·000 0	2·837 6	2·675 2	0·250 00	0·162 38	0·031 25	0·010 42
$3\frac{1}{4}$	4	3·250 0	3·087 6	2·925 2	0·250 00	0·162 38	0·031 25	0·010 42
$3\frac{1}{2}$	4	3·500 0	3·337 6	3·175 2	0·250 00	0·162 38	0·031 25	0·010 42
$3\frac{3}{4}$	4	3·750 0	3·587 6	3·425 2	0·250 00	0·162 38	0·031 25	0·010 42
4	4	4·000 0	3·837 6	3·675 2	0·250 00	0·162 38	0·031 25	0·010 42

*Those requiring full information on American Screw Threads should obtain the National Bureau of Standards Handbook H28, procurable from British Standards Institution, 28 Victoria Street, London, S.W.1.

TABLE NO. 17

AMERICAN NATIONAL FINE (N.F.) THREAD SERIES

Identification		Basic Diameters			Thread Data			
Size	Threads per in.	Major dia-meter	Effec-tive dia-meter	Minor dia-meter	Pitch	Depth of thread	Basic width of flat	Mini-mum width of flat at major diameter of nut
	n	D	E	K	p	h	$p/8$	$p/24$
		in.	in.	in.	in.	in.	in.	in.
0	80	0·060	0·051 9	0·043 8	0·012 50	0·008 12	0·001 56	0·000 52
1	72	0·073	0·064 0	0·055 0	0·013 89	0·009 02	0·001 74	0·000 58
2	64	0·086	0·075 9	0·065 7	0·015 62	0·010 15	0·001 95	0·000 65
3	56	0·099	0·087 4	0·075 8	0·017 86	0·011 60	0·002 23	0·000 74
4	48	0·112	0·098 5	0·084 9	0·020 83	0·013 53	0·002 60	0·000 87
5	44	0·125	0·110 2	0·095 5	0·022 73	0·014 76	0·002 84	0·000 95
6	40	0·138	0·121 8	0·105 5	0·025 00	0·016 24	0·003 12	0·001 04
8	36	0·164	0·146 0	0·127 9	0·027 78	0·018 04	0·003 47	0·001 16
10	32	0·190	0·169 7	0·149 4	0·031 25	0·020 30	0·003 91	0·001 30
12	28	0·216	0·192 8	0·169 6	0·035 71	0·023 20	0·004 46	0·001 49
$\frac{1}{4}$	28	0·250 0	0·226 8	0·203 6	0·035 71	0·023 20	0·004 46	0·001 49
$\frac{5}{16}$	24	0·312 5	0·285 4	0·258 4	0·041 67	0·027 06	0·005 21	0·001 74
$\frac{3}{8}$	24	0·375 0	0·347 9	0·320 9	0·041 67	0·027 06	0·005 21	0·001 74
$\frac{7}{16}$	20	0·437 5	0·405 0	0·372 5	0·050 00	0·032 48	0·006 25	0·002 08
$\frac{1}{2}$	20	0·500 0	0·467 5	0·435 0	0·050 00	0·032 48	0·006 25	0·002 08
$\frac{9}{16}$	18	0·562 5	0·526 4	0·490 3	0·055 56	0·036 08	0·006 94	0·002 31
$\frac{5}{8}$	18	0·625 0	0·588 9	0·552 8	0·055 56	0·036 08	0·006 94	0·002 31
$\frac{3}{4}$	16	0·750 0	0·709 4	0·668 8	0·062 50	0·040 59	0·007 81	0·002 60
$\frac{7}{8}$	14	0·875 0	0·828 6	0·782 2	0·071 43	0·046 39	0·008 93	0·002 98
1	14	1·000 0	0·953 6	0·907 2	0·071 43	0·046 39	0·008 93	0·002 98
$1\frac{1}{8}$	12	1·125 0	1·070 9	1·016 7	0·083 33	0·054 13	0·010 42	0·003 47
$1\frac{1}{4}$	12	1·250 0	1·195 9	1·141 7	0·083 33	0·054 13	0·010 42	0·003 47
$1\frac{3}{8}$	12	1·375 0	1·320 9	1·266 7	0·083 33	0·054 13	0·010 42	0·003 47
$1\frac{1}{2}$	12	1·500 0	1·445 9	1·391 7	0·083 33	0·054 13	0·010 42	0·003 47

The tolerances specified in B.S. 1104 represent the extreme variations allowed on the product. They are such as to produce complete interchangeability and maintain a high grade of product.

The tolerances on diameters of the screw are minus, and are applied from the maximum screw sizes to below the maximum screw sizes.

The tolerances on diameter of the nuts or threaded holes are plus, and are applied from the minimum nut sizes to above the minimum nut sizes.

The tolerances on the thicknesses of threads are minus, and are applied from the maximum thread thickness to below the maximum thread thickness.

TABLE NO. 18

BASIC DIMENSIONS FOR ACME THREADS

Reproduced from B.S. 1104: 1942 (Acme Screw Threads for General Purposes). The Standard thread form is shown in Fig. 107 in this book.

Threads Per Inch	Pitch	Basic Depth of Thread	Total Depth of Thread	Thread Thickness (Basic)	Width of Flat at Crest of Screw (Basic)	Width of Flat at Root of Screw
	in.	in.	in.	in.	in.	in.
10	0·100 00	0·050 00	0·060 0	0·050 00	0·037 1	0·031 9
9	0·111 11	0·055 56	0·065 6	0·055 56	0·041 2	0·036 0
8	0·125 00	0·062 50	0·072 5	0·062 50	0·046 3	0·041 1
7	0·142 86	0·071 43	0·081 4	0·071 43	0·053 0	0·047 8
6	0·166 67	0·083 33	0·093 3	0·083 33	0·061 8	0·056 6
5	0·200 00	0·100 00	0·110 0	0·100 00	0·074 1	0·068 9
4	0·250 00	0·125 00	0·135 0	0·125 00	0·092 7	0·087 5
3½	0·285 71	0·142 86	0·152 9	0·142 86	0·105 9	0·100 7
3	0·333 33	0·166 67	0·176 7	0·166 67	0·123 6	0·118 4
2½	0·400 00	0·200 00	0·210 0	0·200 00	0·148 3	0·143 1
2	0·500 00	0·250 00	0·260 0	0·250 00	0·185 3	0·180 1
1½	0·666 67	0·333 33	0·343 3	0·333 33	0·247 1	0·241 9
1⅓	0·750 00	0·375 00	0·385 0	0·375 00	0·278 0	0·272 8
1	1·000 00	0·500 00	0·510 0	0·500 00	0·370 7	0·365 5

The thread thickness tolerances for a screw and nut of the same diameter and pitch are equal.

The thread thickness tolerances include the effects of pitch and angle errors.

TABLE NO. 19

EFFECTIVE DIAMETER EQUIVALENTS OF ERRORS IN ANGLE

Whitworth Threads **Angle 55°**

EFFECTIVE DIAMETER EQUIVALENT	ERRORS IN ANGLE TO NEAREST 0·1°*																							
in.																								
0·000 1	0·0	0·0	0·0	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·2	0·2	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·3	0·3	0·3	0·4
0·000 2	0·1	0·1	0·1	0·1	0·1	0·2	0·2	0·2	0·2	0·2	0·3	0·3	0·3	0·4	0·4	0·4	0·5	0·5	0·5	0·6	0·6	0·6	0·7	0·8
0·000 3	0·1	0·1	0·1	0·2	0·2	0·2	0·3	0·3	0·3	0·3	0·4	0·5	0·5	0·5	0·6	0·6	0·7	0·7	0·8	0·9	0·9	1·0	1·0	1·1
0·000 4	0·2	0·2	0·2	0·2	0·3	0·3	0·3	0·4	0·4	0·5	0·5	0·6	0·7	0·7	0·8	0·8	0·9	1·0	1·1	1·1	1·2	1·3	1·4	1·5
0·000 5	0·2	0·2	0·2	0·3	0·3	0·4	0·4	0·5	0·5	0·6	0·7	0·8	0·9	0·9	1·0	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·9
0·000 6	0·2	0·3	0·3	0·3	0·4	0·5	0·5	0·6	0·6	0·7	0·8	0·9	1·0	1·1	1·1	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·3
0·000 7	0·3	0·3	0·3	0·4	0·5	0·5	0·6	0·7	0·7	0·8	0·9	1·1	1·2	1·3	1·3	1·5	1·6	1·7	1·9	2·0	2·1	2·3	2·4	2·7
0·000 8	0·3	0·3	0·4	0·5	0·5	0·6	0·7	0·8	0·8	0·9	1·1	1·2	1·4	1·4	1·5	1·7	1·8	2·0	2·1	2·3	2·4	2·6	2·7	3·0
THREADS PER INCH	4	4·5	5	6	7	8	9	10	11	12	14	16	18	19	20	22	24	26	28	30	32	34	36	40

Metric Threads **Angle 60°**

EFFECTIVE DIAMETER EQUIVALENT	ERRORS IN ANGLE TO NEAREST 0·1° *											
in.												
0·000 1	0·4	0·3	0·2	0·2	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·1
0·000 2	0·8	0·5	0·4	0·3	0·3	0·2	0·2	0·2	0·2	0·1	0·1	0·1
0·000 3	1·2	0·8	0·6	0·5	0·4	0·3	0·3	0·3	0·2	0·2	0·2	0·2
0·000 4	1·6	1·0	0·8	0·6	0·5	0·4	0·4	0·3	0·3	0·3	0·3	0·2
0·000 5	1·9	1·3	1·0	0·8	0·6	0·6	0·5	0·4	0·4	0·4	0·3	0·3
0·000 6	2·3	1·6	1·2	0·9	0·8	0·7	0·6	0·5	0·5	0·4	0·4	0·3
0·000 7	2·7	1·8	1·4	1·1	0·9	0·8	0·7	0·6	0·5	0·5	0·5	0·4
0·000 8	3·1	2·0	1·6	1·2	1·0	0·9	0·8	0·7	0·6	0·6	0·5	0·4
MM PITCH	0·50	0·75	1·00	1·25	1·50	1·75	2·00	2·25	2·50	2·75	3·00	3·50

* Sum of errors in the slopes of the opposite flanks regardless of their signs.

B.A. Threads **Angle 47½°**

EFFECTIVE DIAMETER EQUIVALENT	ERRORS IN ANGLE TO NEAREST 0·1° *															
in.																
0·000 1	0·3	0·3	0·3	0·4	0·4	0·4	0·5	0·5	0·6	0·7	0·7	0·8	0·9	1·0	1·1	1·2
0·000 2	0·5	0·6	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·5	1·7	1·8	2·0	2·2	2·4
0·000 3	0·8	0·9	1·0	1·1	1·2	1·3	1·5	1·6	1·8	2·0	2·2	2·5	2·7	3·1	3·3	3·7
0·000 4	1·0	1·1	1·3	1·4	1·6	1·7	1·9	2·1	2·4	2·6	2·9	3·3	3·7	4·1	4·4	4·9
0·000 5	1·3	1·4	1·6	1·8	1·9	2·2	2·4	2·7	3·0	3·3	3·7	4·1	4·6	5·1	5·6	6·1
B.A. No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

*** Sum of errors in the slopes of the opposite flanks regardless of their signs.**

NOTE. Errors in angle virtually increase the effective diameters of plug screw gauges and decrease the effective diameters of ring screw gauges.

TABLE NO. 20

EFFECTIVE DIAMETER EQUIVALENTS OF ERRORS IN PITCH

Error in Pitch	Effective Diameter Equivalent Unit = 0·0001 in.		
	Whit. threads	60° threads	B.A. threads
in.			
0·000 05	1·0	0·9	1·1
0·000 1	1·9	1·7	2·3
0·000 15	2·9	2·6	3·4
0·000 2	3·8	3·5	4·5
0·000 25	4·8	4·3	5·7
0·000 3	5·8	5·2	
0·000 35	6·7	6·1	
0·000 4	7·7	6·9	
0·000 45	8·6	7·8	

TABLE NO. 21

CORRESPONDING PITCHES

(Pitch = 1 ÷ No. of T.P.I.)

T.P.I.	Pitch (in.)	T.P.I.	Pitch (in.)	T.P.I.	Pitch (in.)	T.P.I.	Pitch (in.)
80	0·012 50	28	0·035 71	12	0·083 33	$3\frac{1}{2}$	0·285 71
72	0·013 89	26	0·038 46	11	0·090 91	$3\frac{1}{4}$	0·307 69
64	0·015 62	24	0·041 67	10	0·100 00	3	0·333 33
56	0·017 86	22	0·045 45	9	0·111 11	$2\frac{7}{8}$	0·347 83
48	0·020 83	20	0·050 00	8	0·125 00	$2\frac{3}{4}$	0·363 64
44	0·022 73	19	0·052 63	7	0·142 86	$2\frac{5}{8}$	0·380 95
40	0·025 00	18	0·055 56	6	0·166 67	$2\frac{1}{2}$	0·400 00
36	0·027 78	16	0·062 50	5	0·200 00		
32	0·031 25	14	0·071 43	$4\frac{1}{2}$	0·222 22		
30	0·033 33	13	0·076 92	4	0·250 00		

TABLE NO. 22

FUNCTIONS OF π

$\pi/1 = 3·14159$	$\pi/6 = 0·523599$	$\pi/11 = 0·285599$	$\pi/16 = 0·196350$
$\pi/2 = 1·570796$	$\pi/7 = 0·448799$	$\pi/12 = 0·261799$	$\pi/17 = 0·184800$
$\pi/3 = 1·047198$	$\pi/8 = 0·392699$	$\pi/13 = 0·241661$	$\pi/18 = 0·174533$
$\pi/4 = 0·785398$	$\pi/9 = 0·349066$	$\pi/14 = 0·224399$	$\pi/19 = 0·165347$
$\pi/5 = 0·628319$	$\pi/10 = 0·314593$	$\pi/15 = 0·209440$	$\pi/20 = 0·157080$

TABLE NO. 23

COMPARATIVE—EQUIVALENT PITCHES

For English and Metric Screw Threads, Linear Pitch, Diametral Pitch, and Metric Module Worm Threads

Linear Pitch In.	Linear Pitch mm	T.P.I.	D.P.	Module mm	Circular Pitch In.
0·5000 or $\frac{1}{2}$	12·7	2	6·2832	4·042	$\frac{1}{2}$
0·4947 or $\frac{47}{95}$	12·565		6·35	4·0	
0·4488 or $\frac{35}{78}$	11·4		7·0	3·628	
0·4375 or $\frac{7}{16}$	11·113		7·1808	3·537	$\frac{7}{16}$
0·4329 or $\frac{29}{67}$	11·0		7·2571	3·5	
0·4000 or $\frac{2}{5}$	10·16	$2\frac{1}{2}$	7·854	3·234	$\frac{2}{5}$
0·3927 or $\frac{11}{28}$	9·975		8·0	3·175	
0·3809 5 or $\frac{8}{21}$	9·675	$2\frac{5}{8}$	8·2467		
0·3750 or $\frac{3}{8}$	9·525		8·3776	3·032	$\frac{3}{8}$
0·3711 or $\frac{36}{97}$	9·426		8·4667	3·0	
0·3636 4 or $\frac{4}{11}$	9·235	$2\frac{3}{4}$	8·6394		
0·3491 or $\frac{37}{106}$	8·867		9·0	2·822	
0·3478 3 or $\frac{8}{23}$	8·835	$2\frac{7}{8}$	9·0321		
0·3401 or $\frac{33}{97}$	8·639		9·2364	2·75	
0·3333 3 or $\frac{1}{3}$	8·466	3	9·4248	2·695	$\frac{1}{3}$
0·3149 6 or $\frac{17}{54}$	8·0				
0·3141 6 or $\frac{22}{7}$	7·979		10·0	2·54	
0·3125 or $\frac{5}{16}$	7·937		10·0531	2·526	$\frac{5}{16}$
0·3092 or $\frac{30}{97}$	7·854		10·16	2·5	
0·3076 9 or $\frac{4}{13}$	7·815	$3\frac{1}{4}$	10·2102		
0·2952 or $\frac{31}{105}$	7·5				
0·2857 1 or $\frac{2}{7}$	7·256	$3\frac{1}{2}$	10·9956	2·31	$\frac{2}{7}$
0·2856 or $\frac{2}{7}$	7·254		11·0	2·309	
0·2783 or $\frac{27}{97}$	7·069		11·2889	2·25	
0·2755 9 or $\frac{27}{98}$	7·0				
0·2618 or $\frac{11}{42}$	6·629		12·0	2·117	
0·2560 or $\frac{21}{82}$	6·5				
0·2500 or $\frac{1}{4}$	6·350	4	12·5664	2·021	$\frac{1}{4}$
0·2474 or $\frac{24}{97}$	6·284		12·7	2·0	
0·2417 or $\frac{22}{91}$	6·139		13·0	1·954	
0·2362 2 or $\frac{17}{72}$	6·0				
0·2244 or $\frac{11}{49}$	5·7		14·0	1·814	
0·2222 or $\frac{2}{9}$	5·644	$4\frac{1}{2}$	14·1372	1·796	$\frac{2}{9}$
0·2165 or $\frac{13}{60}$	5·5				
0·2164 or $\frac{21}{97}$	5·497		14·5143	1·75	
0·2094 or $\frac{9}{43}$	5·319		15·0	1·693	
0·2000 or $\frac{1}{5}$	5·08	5	15·708	1·617	$\frac{1}{5}$
0·1968 4 or $\frac{13}{66}$	5·0				
0·1963 or $\frac{21}{107}$	4·986		16·0	1·587	
0·1875 or $\frac{3}{16}$	4·762		16·7552	1·516	$\frac{3}{16}$
0·1855 or $\frac{18}{97}$	4·712		16·9333	1·50	
0·1848 or $\frac{17}{92}$	4·704		17·0	1·494	
0·1771 6 or $\frac{14}{79}$	4·5				
0·1745 or $\frac{15}{86}$	4·432		18·0	1·411	
0·1732 3 or $\frac{13}{75}$	4·4				
0·1666 7 or $\frac{1}{6}$	4·233	6	18·8496	1·347	$\frac{1}{6}$

TABLE NO. 23—(*contd.*)

Linear Pitch In.	Linear Pitch mm	T.P.I.	D.P.	Module mm	Circular Pitch In.
0·1653 or $\frac{19}{115}$	4.2		19·0	1·337	
0·1574 or $\frac{17}{108}$	4·0				
0·1571 or $\frac{11}{70}$	3·990		20·0	1·27	
0·1546 or $\frac{15}{97}$	3·927		20·32	1·25	
0·1428 6 or $\frac{1}{7}$	3·628	7	22·0	1·154	$\frac{1}{7}$
0·1417 3 or $\frac{17}{120}$	3·6				
0·1378 or $\frac{4}{29}$	3·5				
0·1309 or $\frac{11}{84}$	3·325		24·0	1·058	
0·1259 8 or $\frac{15}{119}$	3·2				
0·1250 or $\frac{1}{8}$	3·175	8	25·1328	1·011	$\frac{1}{8}$
0·1237 or $\frac{12}{97}$	3·142		25·4	1·0	
0·1208 or $\frac{7}{58}$	3·068		26·0	0·977	
0·1181 1 or $\frac{13}{110}$	3·0				
0·1122 or $\frac{11}{98}$	2·850		28·0	0·907	
0·1111 or $\frac{1}{9}$	2·822	9	28·2744		$\frac{1}{9}$
0·1102 4 or $\frac{13}{118}$	2·8				
0·1047 or $\frac{11}{105}$	2·659		30·0	0·847	
0·1000 or $\frac{1}{10}$	2·54	10	31·416		$\frac{1}{10}$
0·0984 3 or $\frac{6}{61}$	2·5				
0·0945 or $\frac{7}{74}$	2·4				
0·0937 5 or $\frac{3}{32}$	2·381		32	0·785	
0·0924 or $\frac{11}{119}$	2·352		34	0·747	
0·0909 1 or $\frac{1}{11}$	2·3	11	34·5576		$\frac{1}{11}$
0·0873 or $\frac{9}{103}$	2·216		36	0·706	
0·0866 or $\frac{9}{104}$	2·2				
0·0833 or $\frac{1}{12}$	2·116	12	37·6992		$\frac{1}{12}$
0·0827 or $\frac{9}{109}$	2·1		38	0·668	
0·0787 or $\frac{7}{89}$	2·0				
0·0785 or $\frac{4}{51}$	1·995		40	0·635	
0·0769 or $\frac{1}{13}$	1·954	13	40·8408		$\frac{1}{13}$
0·0748 or $\frac{8}{107}$	1·9		42	0·605	
0·0714 3 or $\frac{1}{14}$	1·814	14	44	0·577	$\frac{1}{14}$
0·0708 7 or $\frac{8}{113}$	1·8				
0·0689 2 or $\frac{2}{29}$	1·75				
0·0683 or $\frac{8}{117}$	1·745		46	0·552	
0·0666 7 or $\frac{1}{15}$	1·693	15	47·124		$\frac{1}{15}$
0·0654 or $\frac{7}{107}$	1·663		48	0·529	
0·0630 or $\frac{7}{111}$	1·6				
0·0628 or $\frac{5}{79}$	1·595		50	0·508	
0·0625 or $\frac{1}{16}$	1·587	16	50·2656	0·505	$\frac{1}{16}$
0·0618 or $\frac{6}{97}$	1·571		50·8	0·5	
0·0590 5 or $\frac{1}{17}$	1·5	17	53·416		$\frac{1}{17}$
0·0561 or $\frac{5}{89}$	1·425		56	0·454	
0·0555 6 or $\frac{1}{18}$	1·411	18	56·5488		$\frac{1}{18}$
0·0551 2 or $\frac{6}{109}$	1·4				
0·0526 3 or $\frac{1}{19}$	1·337	19	59·6906		$\frac{1}{19}$
0·0524 or $\frac{6}{115}$	1·329		60	0·423	
0·0511 8 or $\frac{2}{39}$	1·3				
0·0500 or $\frac{1}{20}$	1·27	20	62·832		$\frac{1}{20}$
0·0492 1 or $\frac{3}{61}$	1·25				

TABLE NO. 24

PRIME NUMBERS AND FACTORS
From 1 to 125

1	—	**26**	2×13	**51**	3×17	**76**	$2^2 \times 19$	**101**	—
2	—	**27**	3^3	**52**	$2^2 \times 13$	**77**	7×11	**102**	$2 \times 3 \times 17$
3	—	**28**	$2^2 \times 7$	**53**	—	**78**	$2 \times 3 \times 13$	**103**	—
4	2^2	**29**	—	**54**	2×3^3	**79**	—	**104**	$2^3 \times 13$
5	—	**30**	$2 \times 3 \times 5$	**55**	5×11	**80**	$2^4 \times 5$	**105**	$3 \times 5 \times 7$
6	2×3	**31**	—	**56**	$2^3 \times 7$	**81**	3^4	**106**	2×53
7	—	**32**	2^5	**57**	3×19	**82**	2×41	**107**	—
8	2^3	**33**	3×11	**58**	2×29	**83**	—	**108**	$2^2 \times 3^3$
9	3^2	**34**	2×17	**59**	—	**84**	$2^2 \times 3 \times 7$	**109**	—
10	2×5	**35**	5×7	**60**	$2^2 \times 3 \times 5$	**85**	5×17	**110**	$2 \times 5 \times 11$
11	—	**36**	$2^2 \times 3^2$	**61**	—	**86**	2×43	**111**	3×37
12	$2^2 \times 3$	**37**	—	**62**	2×31	**87**	3×29	**112**	$2^4 \times 7$
13	—	**38**	2×19	**63**	$3^2 \times 7$	**88**	$2^3 \times 11$	**113**	—
14	2×7	**39**	3×13	**64**	2^6	**89**	—	**114**	$2 \times 3 \times 19$
15	3×5	**40**	$2^3 \times 5$	**65**	5×13	**90**	$2 \times 3^2 \times 5$	**115**	5×23
16	2^4	**41**	—	**66**	$2 \times 3 \times 11$	**91**	7×13	**116**	$2^2 \times 29$
17	—	**42**	$2 \times 3 \times 7$	**67**	—	**92**	$2^2 \times 23$	**117**	$3^2 \times 13$
18	2×3^2	**43**	—	**68**	$2^2 \times 17$	**93**	3×31	**118**	2×59
19	—	**44**	$2^2 \times 11$	**69**	3×23	**94**	2×47	**119**	7×17
20	$2^2 \times 5$	**45**	$3^2 \times 5$	**70**	$2 \times 5 \times 7$	**95**	5×19	**120**	$2^3 \times 3 \times 5$
21	3×7	**46**	2×23	**71**	—	**96**	$2^5 \times 3$	**121**	11^2
22	2×11	**47**	—	**72**	$2^3 \times 3^2$	**97**	—	**122**	2×61
23	—	**48**	$2^4 \times 3$	**73**	—	**98**	2×7^2	**123**	3×41
24	$2^3 \times 3$	**49**	7^2	**74**	2×37	**99**	$3^2 \times 11$	**124**	$2^2 \times 31$
25	5^2	**50**	2×5^2	**75**	3×5^2	**100**	$2^2 \times 5^2$	**125**	5^3

TABLE NO. 25

METRIC CONVERSION TABLES

(Reproduced from B.S. Handbook No. 2, by permission)

Inches to Millimetres

1 Inch = 25·4 Millimetres

In.	mm	In.	mm	In.	mm	In.	mm
0·000 1	0·002 54	0·001	0·025 4	0·01	0·254	0·1	2·54
0·000 2	0·005 08	0·002	0·050 8	0·02	0·508	0·2	5·08
0·000 3	0·007 62	0·003	0·076 2	0·03	0·762	0·3	7·62
0·000 4	0·010 16	0·004	0·101 6	0·04	1·016	0·4	10·16
0·000 5	0·012 70	0·005	0·127 0	0·05	1·270	0·5	12·70
0·000 6	0·015 24	0·006	0·152 4	0·06	1·524	0·6	15·24
0·000 7	0·017 78	0·007	0·177 8	0·07	1·778	0·7	17·78
0·000 8	0·020 32	0·008	0·203 2	0·08	2·032	0·8	20·32
0·000 9	0·022 86	0·009	0·228 6	0·09	2·286	0·9	22·86

In.			mm	In.			mm	In.			mm
		1/64	0·396 9		11/32		8·731 2			43/64	17·065 6
	1/32		0·793 8			23/64	9·128 1	11/16			17·462 5
		3/64	1·190 6	3/8			9·525 0			45/64	17·859 4
1/16			1·587 5			25/64	9·921 9		23/32		18·256 2
		5/64	1·984 4		13/32		10·318 7			47/64	18·653 1
	3/32		2·381 2			27/64	10·715 6	3/4			19·050 0
		7/64	2·778 1	7/16			11·112 5			49/64	19·446 9
1/8			3·175·0			29/64	11·509 4		25/32		19·843 7
		9/64	3·571 9		15/32		11·906 2			51/64	20·240 6
	5/32		3·968 7			31/64	12·303 1	13/16			20·637 5
		11/64	4·365 6	1/2			12·700 0			53/64	21·034 4
3/16			4·762 5			33/64	13·096 9		27/32		21·431 2
		13/64	5·159 4		17/32		13·493 7			55/64	21·828 1
	7/32		5·556 2			35/64	13·890 6	7/8			22·225 0
		15/64	5·953 1	9/16			14·287 5			57/64	22·621 9
1/4			6·350 0			37/64	14·684 4		29/32		23·018 7
		17/64	6·746 9		19/32		15·081 2			59/64	23·415 6
	9/32		7·143 7			39/64	15·478 1	15/16			23·812 5
		19/64	7·540 6	5/8			15·875 0			61/64	24·209 4
5/16			7·937 5			41/64	16·271 9		31/32		24·606 2
		21/64	8·334 4		21/32		16·668 7			63/64	25·003 1

In.		10	20	30	In.		10	20	30
0	—	254·0	508·0	762·0	5	127·0	381·0	635·0	889·0
1	25·4	279·4	533·4	787·4	6	152·4	406·4	660·4	914·4
2	50·8	304·8	558·8	812·8	7	177·8	431·8	685·8	939·8
3	76·2	330·2	584·2	838·2	8	203·2	457·2	711·2	965·2
4	101·6	355·6	609·6	863·6	9	228·6	482·6	736·6	990·6

PRINCIPAL THREAD STANDARDIZATION AUTHORITIES

British Standards Institution, (B.S.I.), 28 Victoria Street, London, S.W.1.

The National Bureau of Standards, U.S. Department of Commerce, Washington, D.C., U.S.A.

Canadian Engineering Standards Association, 79 Sussex Street, Ottawa, Ontario, Canada.

Comité de Normalisation de la Mécanique, 92 Rue de Courcelles, Paris (8e), France.

Statens Provningsanstalt, Ministry of Commerce, Stockholm, Sweden.

International Federation of National Standardizing Associations, 57 Spalentorweg, Basle, Switzerland.

Deutscher Normenausschus, 47 Dorotheenstrasse, Berlin, Germany.

SOME USEFUL REFERENCE BOOKS

Notes on Screw Gauges. (Compiled at the National Physical Laboratory. Published by H.M.S.O.)

Machinery's Screw Thread Book. (Published by Machinery Publishing Co.)

Screw Thread Cutting and Measurement, by A. C. Parkinson. (Published by Pitman.)

Workshop Precision Grinding. (Published by the Churchill Machine Tool Co.)

Engineering Precision Measurements, by A. W. Judge. (Published by Chapman & Hall, Ltd.)

The Use, Care and Protection of Abrasive Wheels. (Published by the American Standards Association and obtainable from the B.S.I.)

Screw Thread Standards For Federal Services. U.S. National Bureau of Standards Handbook H 28. (Obtainable from the B.S.I.)

Gears, Gear Production and Measurement, by A. C. Parkinson and W. H. Dawney. (Published by Pitman.)

Engineering Inspection, by A. C. Parkinson. (Published by Pitman.)

BRITISH STANDARD SPECIFICATIONS OF PARTICULAR INTEREST TO THREAD-GRINDING PERSONNEL

	B.S. NO.
Screw Threads of Whitworth Form	84
British Association Screw Threads	93
British Standard Cycle Threads	811
British Standard Pipe Threads	21
Metric Screw Threads, Système International	1095
Screw Thread Gauge Tolerances	919
Screwing Taps	949
Acme Screw Threads	1104
Designs for Plug, Ring and Gap Gauges	1044

British Standards for Workshop Practice. (This is a summary of various British Standards, alternatively known as B.S. Handbook No. 2. Standard dimensions of gear hobs are given in this book.)

A list of British Standards, specially connected with mechanical engineering, is obtainable post-free from the British Standards Institution.

USEFUL TABLES IN PRECEDING CHAPTERS

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TABLE NO. 26

(Pages 216 to 224)

USEFUL COMPARISON TABLE OF BRITISH, AMERICAN AND CONTINENTAL STANDARDS FOR SCREW THREADS

Notes. This unique comparison table is published by arrangement with Messrs. Alfred Herbert, Ltd., Coventry, who own the copyright.

COLUMN 1. The pitches given in this column for diameters below $\frac{1}{4}$ in. are the old Whitworth standard, and are not specified in the B.S. Specification for British Standard Whitworth Threads. The particulars are given here because many of these small sizes are still in use. Conduit threads are used for conduits and fittings for electric wiring. The form is Whitworth standard. See B.S. No. 91.

COLUMN 3. A.D.M. Fine means Admiralty Fine, a system of Whitworth form used for marine engine and boiler accessories, etc.

COLUMNS 7 to 12. These give the old standards of American Threads which are still in use. Columns 13 and 14 give the new standards, American National Coarse (N.C.) and American National Fine (N.F.).

COLUMNS 10 and 15. These two columns give the numbers by which A.S.M.E. and B.A. threads are generally specified.

COLUMN 24. This column gives the nominal pipe size for which the full diameter of the screw is given in column *b*.

COLUMN 25. The pitches for Class II, B.S.P. parallel threads are given opposite the actual full diameter of the screw thread. This diameter is also the gauge diameter for the Class I, B.S.P. taper threads, the pitches for which are given opposite the outside diameter of the pipe. Briggs, or American National, pipe threads have 60° angles, are usually cut with sharp V roots, but have truncated crests.

COLUMNS 17 and 19. The Swiss Standard system follows the Système International very closely over 6 mm. diameter up to 80 mm. diameter.

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Screw Thread Systems			British Threads						American Threads								Metric Threads									Pipe Threads			
			B.S. Whit.	B.S. Fine	A.D.M. Fine	C.E.I.	Brass	Conduit	U.S.S.	S.A.E. Reg.	S.A.E. Fine	A.S.M.E. No.	A.S.M.E. Std.	A.S.M.E. Spec.	N.C.	N.F.	B.A. No.	B.A.	S.I.	Metric Fine	Swiss Std.	Swiss Fine	S.I. (D.I.N.)	S.I. Fine (D.I.N.)	Löwenherz	Pipe Sizes	B.S.P.	Briggs	Copper Tube
Thread Form			*a*	*a*	*a*	*e*	*a*	*a*	*b*	*b*	*b*		*b*	*b*	*b*	*b*		*c*	*d*	*d*	*d*	*d*	*f*	*f*	*h*		*a*	*g*	*a*
Thread Angle			55	55	55	60	55	55	60	60	60		60	60	60	60		47½	60	60	60	60	60	60	53°8′		55	60	55
Full Dia. of Screw			Threads per Inch						Threads per Inch								Pitch in Millimetres									Threads per Inch			
Ins.	Ins.	mm																											
	0·0311	0·79	...	...	...	...	...	...	...	...	...	...	...	...	...	...	16	0·19											
	0·0354	0·90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	15	0·21											
	0·0394	1·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	14	0·23	0·25	0·20	0·25	0·12	0·25	0·20	0·25				
	0·0472	1·20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	13	0·25	0·25	0·20	0·25	0·12	0·25	0·20	0·25				
	0·0511	1·30	...	...	...	...	...	...	...	...	...	...	...	...	...	...	12	0·28											
	0·0551	1·40	...	...	...	...	...	...	...	...	...	...	...	...	...	...			0·30	0·20	0·30	0·12	0·30	0·20	0·30				
17 S.W.G.	0·0560		...	...	...	62																							
	0·0591	1·50	...	...	...	...	...	...	...	...	...	...	...	...	...	...	11	0·31											
	0·0600	......	...	...	...	...	...	...	...	...	...	0	80	...	...	80													
1/16	0·0625	......	60																										
16 S.W.G.	0·0640	......	...	...	...	62																							
	0·0669	1·70	...	...	...	...	...	...	...	...	...	...	...	...	...	...	10	0·35	0·35	0·20	0·35	0·20	0·35	0·20	0·35				
15 S.W.G.	0·0720	......	...	...	...	62																							
	0·0730	......	...	...	...	...	...	...	...	...	...	1	72	64	64	72													
	0·0748	1·90	...	...	...	...	...	...	...	...	...	...	...	...	...	...	9	0·39											
5/64	0·0781	......	56																										
	0·0787	2·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	0·40	0·25	0·40	0·25	0·40	0·20	0·40				
14 S.W.G.	0·0800	......	...	...	...	62																							

a	*b*	*c*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	0·0860											2	64	56	56	64													
	0·0866	2·20															8	0·43											
	0·0906	2·30																	0·40	0·25	0·40	0·25	0·40	0·20	0·40				
13 S.W.G.	0·0920					56																							
$\frac{3}{32}$	0·0937		48																										
	0·0984	2·50															7	0·48											
	0·0990											3	56	48	48	56													
	0·1024	2·60																	0·45	0·35	0·45	0·25	0·45	0·25	0·45				
12 S.W.G.	0·1040					44																							
$\frac{7}{64}$	0·1094		48																										
	0·1102	2·80															6	0·53											
	0·1120											4	48	(40 (36	40	48													
	0·1181	3·00																	0·60	0·35	0·50	0·35	0·50	0·35	0·50				
$\frac{1}{8}$	0·1250		40			40	26					5	44	(40 (36	40	44													
	0·1260	3·20															5	0·59											
	0·1378	3·50																	0·60	0·35	0·60	0·35	0·60	0·35	0·60				
	0·1380											6	40	(36 (32	32	40													
$\frac{9}{64}$	0·1406		40																										
	0·1417	3·60															4	0·66											
	0·1510											7	36	(32 (30															
	0·1540					40																							
$\frac{5}{32}$	0·1562		32			32																							
	0·1575	4·00																	0·75	0·50	0·70	0·50	0·70	0·35	0·70				
	0·1614	4·10															3	0·73											
	0·1640											8	36	(32 (30	32	36													
$\frac{11}{64}$	0·1719		32																										
	0·1750					32																							
	0·1770											9	32	(30 (24															
	0·1772	4·50																	0·75	0·50	0·75	0·50	0·75	0·50	0·75				
	0·1850	4·70															2	0·81											
$\frac{3}{16}$	0·1875		24	32		32	26				32																		
	0·1900											10	30	(32 (24	24	32													
	0·1969	5·00																	0·90	0·50	0·80	0·50	0·80	0·50	0·80				

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Screw Thread Systems			British Threads						American Threads								Metric Threads									Pipe Threads			
			B.S. Whit.	B.S. Fine	A.D.M. Fine	C.E.I.	Brass	Conduit	U.S.S.	S.A.E. Reg.	S.A.E. Fine	A.S.M.E. No.	A.S.M.E. Std.	A.S.M.E. Spec.	N.C.	N.F.	B.A. No.	B.A.	S.I.	Metric Fine	Swiss Std	Swiss Fine	S.I. (D.I.N.)	S.I. Fine (D.I.N.)	Löwenherz	Pipe Sizes	B.S.P.	Briggs	Copper Tube
Thread Form			*a*	*a*	*a*	*e*	*a*	*a*	*b*	*b*	*b*		*b*	*b*	*b*	*b*		*c*	*d*	*d*	*d*	*d*	*f*	*f*	*h*		*a*	*g*	*a*
Thread Angle			55	55	55	60	55	55	60	60	60		60	60	60	60		47½	60	60	60	60	60	60	53°8′		55	60	55
Full Dia. of Screw			Threads per Inch						Threads per Inch								Pitch in Millimetres									Threads per Inch			
Ins.	Ins.	mm																											
13/64	0·2031		24																										
	0·2087	5·30															1	0·9											
	0·2160											12	28	24	24	28													
	0·2165	5·50																			0·90	0·50	0·90	0·50	0·90				
7/32	0·2187		24	28		26																							
15/64	0·2344		24																										
	0·2362	6·00															0	1·0	1·0	0·75	1·0	0·75	1·0	0·75	1·0				
	0·2420				24							14	24	20															
	0·2480																									1/8			28
1/4	0·2500		20	26	24	26	26		20	28	36				20	28													
	0·2660					26																							
	0·2680											16	22	20															
	0·2756	7·00																	1·0	0·75	1·0	0·75	1·0	0·75	1·10				
9/32	0·2813			26	24	26	26																						
	0·2940											18	20	18															
5/16	0·3125		18	22	24	26	26		18	24	32				18	24													
	0·3150	8·00																	1·25	1·00	1·25	1·00	1·25	0·75	1·20				
	0·3200						26					20	20	18															

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	0·3460											22	18	16															
	0·3543	9·00																	1·25	1·00	1·25	1·00	1·25	1·00	1·30				
	0·3720											24	16	18															
3/8	0·3750		16	20	24	26	26		16	24	32				16	24													
	0·3830																									1/8	28		
	0·3890																									1/4			20
	0·3937	10·00			24														1·50	1·00	1·50	1·00	1·50	1·00	1·40				
	0·3980											26	16	14															
	0·4044																									1/8		27	
	0·4240											28	14	16															
	0·4331	11·00																			1·50	1·00	1·50	1·00					
7/16	0·4375		14	18	24	26	26		14	20	28				14	20													
	0·4500											30	14	16															
	0·4724	12·00					26												1·75	1·50	1·75	1·25	1·75	1·50	1·60				
1/2	0·5000		12	16	20	26	26	18	13	20	28				13	20													
	0·5140																									3/8			20
	0·5180																									1/4	19		
	0·5343																									1/4		18	
	0·5512	14·00			20	26	26												2·0	1·50	2·0	1·25	2·0	1·50	1·80				
9/16	0·5625		12	16	20	20	26		12	18	24				12	18													
5/8	0·6250		11	14	20		26	18	11	18	24				11	18													
	0·6299	16·00																	2·0	1·50	2·00	1·25	2·00	1·50	2·00				
	0·6390																									1/2			20
	0·6560																									3/8	19		
	0·6714																									3/8		18	
11/16	0·6875		11	14	20		26	16		16	24																		
	0·7087	18·00																	2·50	1·50	2·50	1·50	2·50	1·50	2·20				
3/4	0·7500		10	12	14		26	16	10	16	20				10	16													
	0·7640																									5/8			20
	0·7874	20·00																	2·50	1·50	2·50	1·50	2·50	1·50	2·40				
13/16	0·8125		10	12	14		26	16																					
	0·8250				14																					1/2	14		
	0·8355																									1/2		14	
	0·8661	22·00																	2·50	1·50	2·50	1·50	2·50	1·50	2·80				
7/8	0·8750		9	11	14		26	16	9	14	20				9	14													
	0·8890																									3/4			20
	0·9020																									5/8	14		
15/16	0·9375		9		14		26																						
	0·9449	24·00																	3·0	2·00	3·00	1·50	3·00	1·50	2·80				
	0·9675					30																							

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Screw Thread Systems			British Threads						American Threads								Metric Threads									Pipe Threads			
			B.S. Whit.	B.S. Fine	A.D.M. Fine	C.E.I.	Brass	Conduit	U.S.S.	S.A.E. Reg.	S.A.E. Fine	A.S.M.E. No.	A.S.M.E. Std.	A.S.M.E. Spec.	N.C.	N.F.	B.A. No.	B.A.	S.I.	Metric Fine	Swiss Std.	Swiss Fine	S.I. (D.I.N.)	S.I. Fine (D.I.N.)	Löwenherz	Pipe Sizes	B.S.P.	Briggs	Copper Tube
Thread Form			*a*	*a*	*a*	*e*	*a*	*a*	*b*	*b*	*b*		*b*	*b*	*b*	*b*		*c*	*d*	*d*	*d*	*d*	*f*	*f*	*h*		*a*	*g*	*a*
Thread Angle			55	55	55	60	55	55	60	60	60		60	60	60	60		47½	60	60	60	60	60	60	53°8′		55	60	55
Full Dia. of Screw			Threads per Inch						Threads per Inch								Pitch in Millimetres									Threads per Inch			
Ins.	**Ins.**	**mm**																											
1	1·000	25·40	8	10	12	26	26	16	8	14	20				8	14													
	1·014																									7/8			20
	1·0236	26·00																							3·20				
	1·0410																									3/4	14		
	1·0460																									3/4		14	
	1·0630	27·00																	3·00	2·00	3·00	2·00	3·00	1·50					
	1·1024	28·00																							3·20				
1⅛	1·1250		7	9	12		26		7	12	18				7	12													
	1·1550																									1			20
	1·1811	30·00																	3·50	2·00	3·50	2·00	3·50	1·50	3·60				
	1·1890																									7/8	14		
1¼	1·2500		7	9	12		26	16	7	12	18				7	12													
	1·2598	32·00																							3·60				
	1·2900					24																							
	1·2992	33·00																	3·50	2·00	3·50	2·00	3·50	1·50					
	1·3082																									1		11½	
	1·3090																									1	11		
	1·3700					24																							

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
$1\frac{3}{8}$	1·3750	......	6	8	12	24	26	16	6	12	18	...	...	...	6	12													
	1·4050	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{4}$	...	...	20
	1·4173	36·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	4·00	3·00	4·00	2·00	4·00	1·50	4·00				
$1\frac{7}{16}$	1·4375	......	..	..	12	24	26	..																					
$1\frac{1}{2}$	1·5000	......	6	8	12	24	26	14	6	12	18	...	...	...	6	12													
	1·5354	39·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	4·00	3·00	4·00	2·00	4·00						
	1·5748	40·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1·50	4·40				
$1\frac{5}{8}$	1·6250	......	5	8	12	..	..	..	$5\frac{1}{2}$	12	16																		
	1·6500	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{4}$	11		
	1·6530	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{4}$	..	$11\frac{1}{2}$	
	1·6536	42·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	4·50	3·00	4·50	2·00	4·50	1·50					
	1·6550	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{2}$	...	...	20
$1\frac{3}{4}$	1·7500	......	5	7	12	..	..	14	5	12	16	...	...	...	5														
	1·7716	45·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	4·50	3·00	4·50	2·00	4·50	1·50					
$1\frac{7}{8}$	1·8750	......	$4\frac{1}{2}$	7	12	..	..	..	5	12	16																		
	1·8820	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{2}$	11		
	1·8898	48·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	5·00	3·00	5·00	2·00	5·00	1·50					
	1·8919	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{1}{2}$	..	$11\frac{1}{2}$	
	1·9290	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{3}{4}$	...	...	16
	1·9685	50·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1·50					
2	2·0000	......	$4\frac{1}{2}$	7	8	..	..	14	$4\frac{1}{2}$	12	16	...	...	...	$4\frac{1}{2}$														
	2·0472	52·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	5·00	3·00	5·00	2·50	5·00	1·50					
	2·1160	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$1\frac{3}{4}$	11		
$2\frac{1}{8}$	2·1250	......	$4\frac{1}{2}$	..	8	..	..	..	...	12	16																		
	2·1790	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	16
	2·2047	56·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	5·50	4·00	5·50	2·50	5·50	2·00					
$2\frac{1}{4}$	2·2500	......	4	6	8	..	..	..	$4\frac{1}{2}$	12	16	...	...	...	$4\frac{1}{2}$														
	2·3470	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	11		
	2·3622	60·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	5·50	4·00	5·50	2·50	5·50	2·00					
	2·3659	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	$11\frac{1}{2}$	
$2\frac{3}{8}$	2·3750	......	4	..	8	..	..	..	...	12	16																		
	2·4290	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$2\frac{1}{4}$	...	...	16
$2\frac{1}{2}$	2·5000	......	4	6	8	..	..	14	4	12	16	...	...	...	4														
	2·5197	64·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	6·00	4·00	6·00	2·50	6·00	2·00					
	2·5870	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$2\frac{1}{4}$	11		
$2\frac{5}{8}$	2·6250	......	4	..	8	..	..	..	...	12	16																		
	2·6772	68·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	6·00	....	6·00	2·50	6·00	2·00					
	2·6790	......	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	$2\frac{1}{2}$	...	...	16
$2\frac{3}{4}$	2·7500	......	$3\frac{1}{2}$	6	8	..	..	..	4	12	16	...	...	...	4														
	2·8347	72·00	..	..	..	..	..	..	...	...	...	...	...	...	...	...	...	...	6·00	4·00	6·00	2·50	6·00	2·00					

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Screw Thread Systems			British Threads						American Threads								Metric Threads									Pipe Threads			
			B.S. Whit.	B.S. Fine	A.D.M. Fine	C.E.I.	Brass	Conduit	U.S.S.	S.A.E. Reg.	S.A.E. Fine	A.S.M.E. No.	A.S.M.E. Std.	A.S.M.E. Spec.	N.C.	N.F.	B.A. No.	B.A.	S.I.	Metric Fine	Swiss Std.	Swiss Fine	S.I. (D.I.N.)	S.I. Fine (D.I.N.)	Löwenherz	Pipe Sizes	B.S.P.	Briggs	Copper Tube
Thread Form			*a*	*a*	*a*	*e*	*a*	*a*	*b*	*b*	*b*		*b*	*b*	*b*	*b*		*c*	*d*	*d*	*d*	*d*	*f*	*f*	*h*		*a*	*g*	*a*
Thread Angle			55	55	55	60	55	55	60	60	60		60	60	60	60		47½	60	60	60	60	60	60	53°8′		55	60	55
Full Dia. of Screw			Threads per Inch						Threads per Inch								Pitch in Millimetres									Threads per Inch			
Ins.	Ins.	mm																											
	2·8622																									2½		8	
2⅞	2·8750		3½		8					12	16																		
	2·9290																									2¾			16
	2·9600																									2½	11		
	2·9921	76·00																	6·00		6·00	2·50	6·00	2·00					
3	3·000		3½	5	8				3½	10	16				4														
3⅛	3·1250		3½		8				3½	10	16				4														
	3·1496	90·00																	6·00	4·00	6·00	2·50	6·00	2·00					
	3·2030																									3			16
	3·2100																									2¾	11		
3¼	3·2500		3¼		8				3¼	10	16				4														
	3·3071	84·00																					6·00						
	3·3465	85·00																						2·00					
3⅜	3·3750		3¼		8					10	16																		
	3·4530																									3¼			16
	3·4600																									3	11		
	3·4885																									3		8	
3½	3·5000		3¼		8				3¼	10	16				4														

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	3·5039	89·00																					6·00						
	3·5433	90·00																						2·00					
3⅝	3·6250		3¼		8					10	16																		
	3·7000																									3¼	11		
	3·7008	94·00																					6·00						
	3·7270																									3½			16
	3·7402	95·00																						2·00					
3¾	3·7500		3		8				3	10	16																		
3⅞	3·8750		3		8					10	16																		
	3·8976	99·00																					6·00						
	3·9370	100·00																						2·00					
	3·9500																									3½	11		
	3·977																									3¾			16
	3·9888																									3½		8	
4	4·0000		3		6				3	10	16				4														
	4·0158	102·00																						3·00					
	4·0945	104·00																					6·00						
4⅛	4·125		3		6					10	16																		
	4·1339	105·00																						3·00					
	4·2000																									3¾	11		
4¼	4·2500		2⅞		6					10	16																		
	4·2510																									4			16
	4·2520	108·00																						3·00					
	4·2913	109·00																					6·00						
	4·3307	110·00																						3·00					
4⅜	4·375		2⅞		6					10	16																		
	4·4094	112·00																						3·00					
	4·4500																									4	11		
	4·4871																									4		8	
	4·4882	114·00																					6·00						
4½	4·5000		2⅞		6				2¾	10	16																		
	4·5276	115·00																						3·00					
4⅝	4·6250		2⅞		6					10	16																		
	4·6458	118·00																						3·00					
	4·6852	119·00																											
	4·7244	120·00																						3·00					
4¾	4·7500		2¾		6				2⅝	10	16																		
	4·8032	122·00																						3·00					
4⅞	4·8750		2¾		6					10	16																		
	4·8820	124·00																					6·00						

a	b	c	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Screw Thread Systems			British Threads						American Threads								Metric Threads									Pipe Threads			
			B.S. Whit.	B.S. Fine	A.D.M. Fine	C.E.I.	Brass	Conduit	U.S.S.	S.A.E. Reg.	S.A.E. Fine	A.S.M.E. No.	A.S.M.E. Std.	A.S.M.E. Spec.	N.C.	N.F.	B.A. No.	B.A.	S.I.	Metric Fine	Swiss Std.	Swiss Fine	S.I. (D.I.N.)	S.I. Fine (D.I.N.)	Löwenherz	Pipe Sizes	B.S.P.	Briggs	Copper Tube
Thread Form			*a*	*a*	*a*	*e*	*a*	*a*	*b*	*b*	*b*		*b*	*b*	*b*	*b*		*c*	*d*	*d*	*d*	*d*	*f*	*f*	*h*		*a*	*g*	*a*
Thread Angle			55	55	55	60	55	55	60	60	60		60	60	60	60		47½	60	60	60	60	60	60	53°8′		55	60	55
Full Dia. of Screw			Threads per Inch						Threads per Inch								Pitch in Millimetres									Threads per Inch			
Ins.	Ins.	mm																											
	4·9214	125·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
	4·9500	......	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4½	11		
	4·9859	......	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	4½	...	8	
5	5·0000	......	2¾	...	6	...	...	...	2½	10	16																		
	5·0395	128·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
	5·0785	129·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6·00						
	5·1182	130·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
5⅛	5·1250																												
	5·1969	132·00	...	...	6	...	...	...	...	10	16	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
5¼	5·2500	......	2⅝	...	6	...	...	...	...	10	16																		
	5·2757	134·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6·00						
	5·3151	135·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
5⅜	5·3750	......	...	...	6	...	...	...	...	10	16																		
	5·4332	138·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	3·00					
	5·4500	......	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	11		
	5·4725	139·00	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	6·00						
5½	5·5000	......	2⅝	...	6	...	...	...	2⅜	10	16																		

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